mAEWing1 Design Review

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OUR TEAM

- University of Minnesota
- Systems Technology Inc.
- Virginia Polytechnic Institute and State University
- Aurora Flight Sciences
- CM Soft Inc.
- Schmidt and Associates

AGENDA

- Purpose
- Objectives
  - Program
  - mAEWing1
- Design
  - Overview
  - Airframe
  - Systems
  - Build Plan
  - Software
  - Test Plan
- Current Status

Design Review Objectives and Success Criteria

- Ensure alignment of design and flight test with NRA and NASA Fixed Wing objectives
- Review and comment on approach to mAEWing1 vehicle, vehicle design, and testing
- Beyond preliminary design, but short of firm design
  - Investigating accelerometers and camera system
  - Minor changes to aircraft structure, hard points, etc as build progresses
  - Modeling and control law approach firm, but the models and control laws will be developed as the aircraft build progresses
- Deliverables:
  - Presentation
  - Published wing design
    - Currently published on our git repository, will be archived on the digital conservancy once in a firm state

NASA Subsonic Transport System Level Metrics

…. technology for dramatically improving noise, emissions, & performance

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-71 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption‡ (rel. to 2005 best in class)	-33%	-50%	-60%

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines, N+2 values are referenced to a 777-200 with GE90 engines

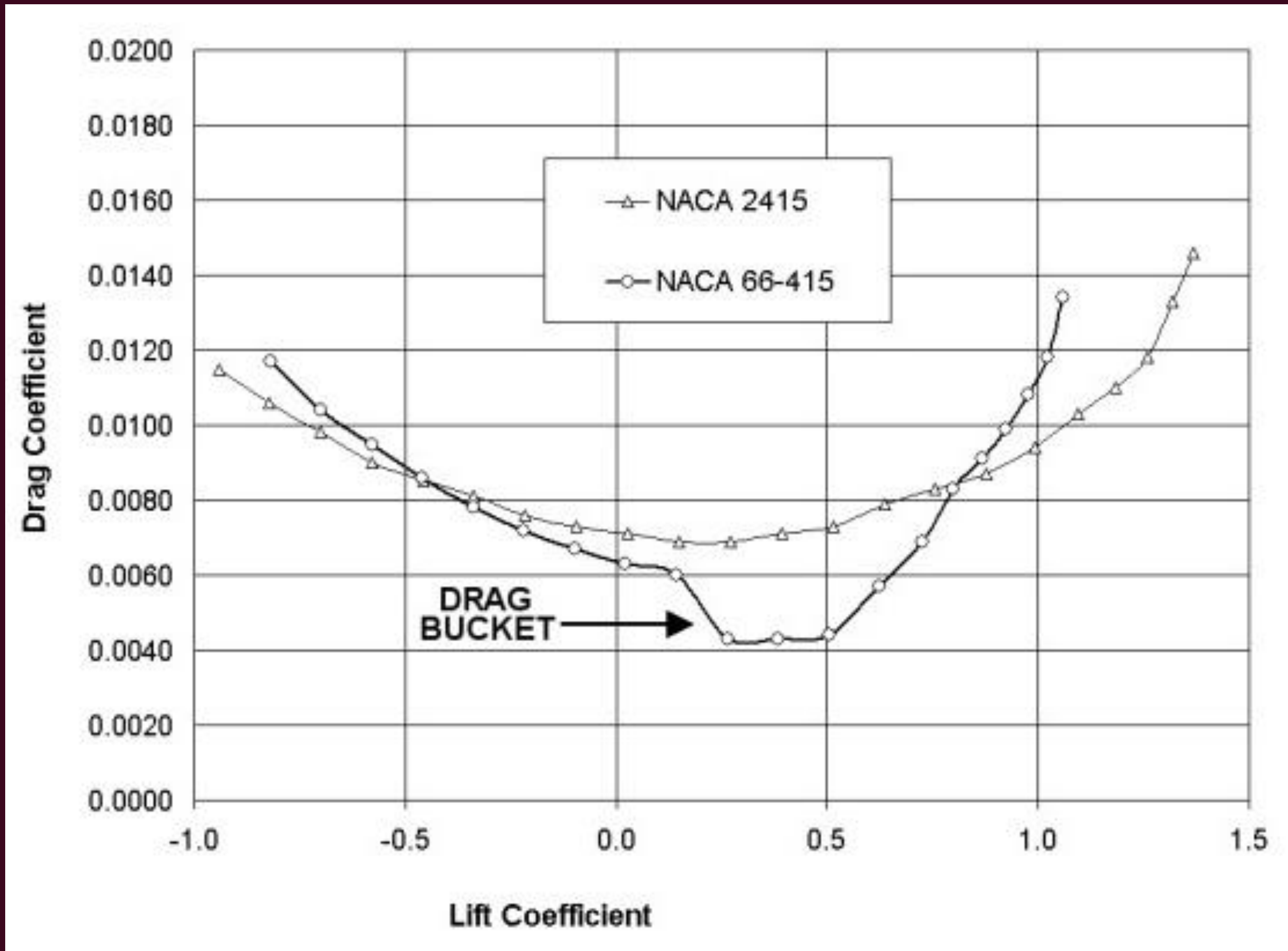
** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

‡ CO_2 emission benefits dependent on life-cycle CO_{2e} per MJ for fuel and/or energy source used

MOTIVATION

- Commercial aircraft are designed for a single operating point
  - Off condition weight, altitude, and speed decrease efficiency
  - Compromise between cruise speed and meeting landing requirements
  - Poor low speed characteristics require use of many flaps and slats

➡ High fuel burn and noise



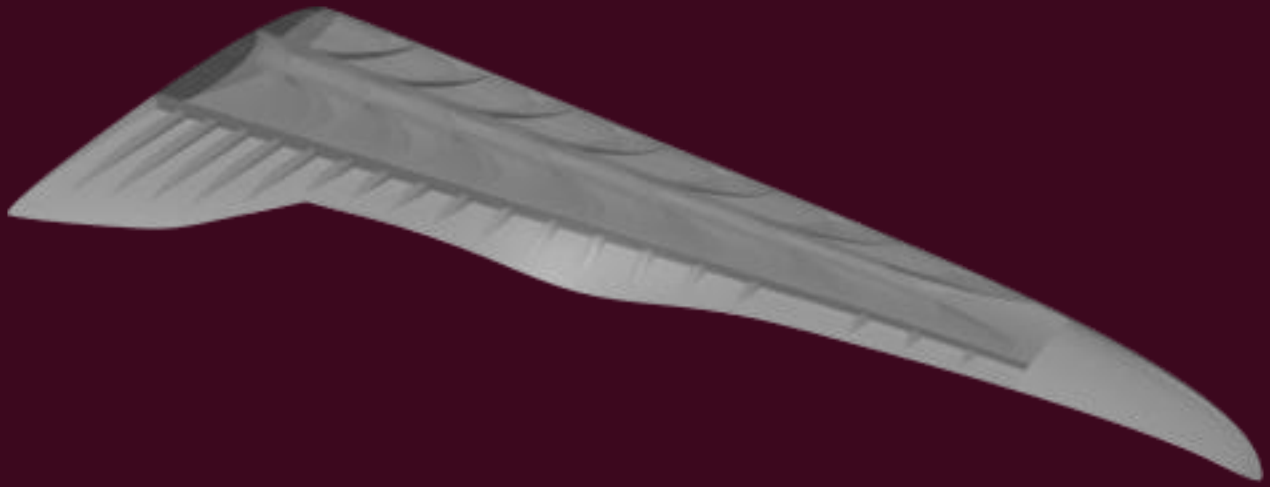
MOTIVATION

- Long, high aspect ratio wings are more aerodynamically efficient, but pose potential stiffness problems
  - Traditional aircraft design approaches favor stiff wings
  - High stiffness would lead to increased weight, negatively impacting fuel burn

➡ Expand the aircraft design space to take advantage of wing flexibility

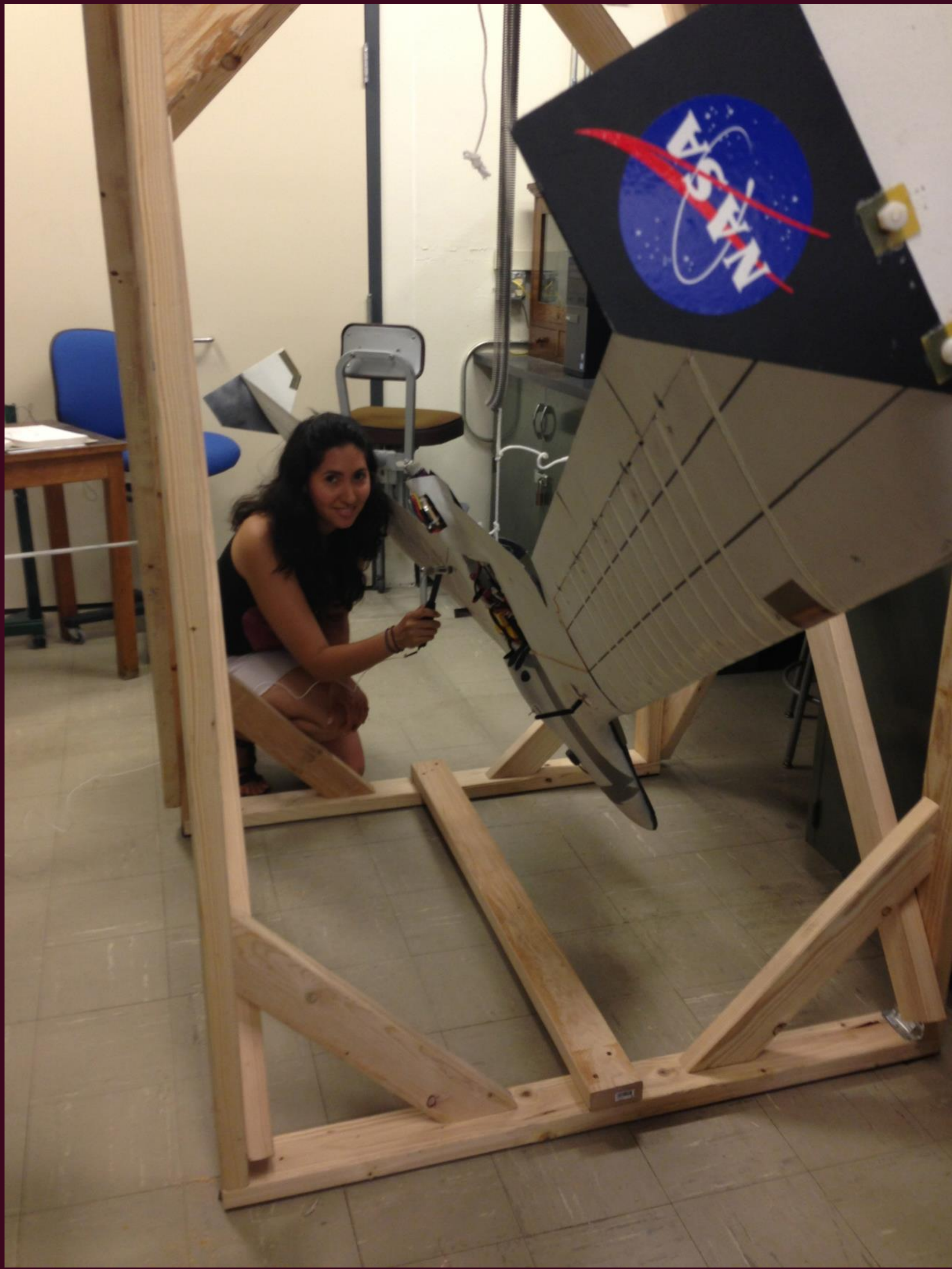
OBJECTIVE

- Research and develop performance adaptive wing for N+3 aircraft
  - Adapt wing to flight condition:
    - Minimize fuel burn in cruise
    - Maximize lift for takeoff
    - Maximize lift and drag for landing



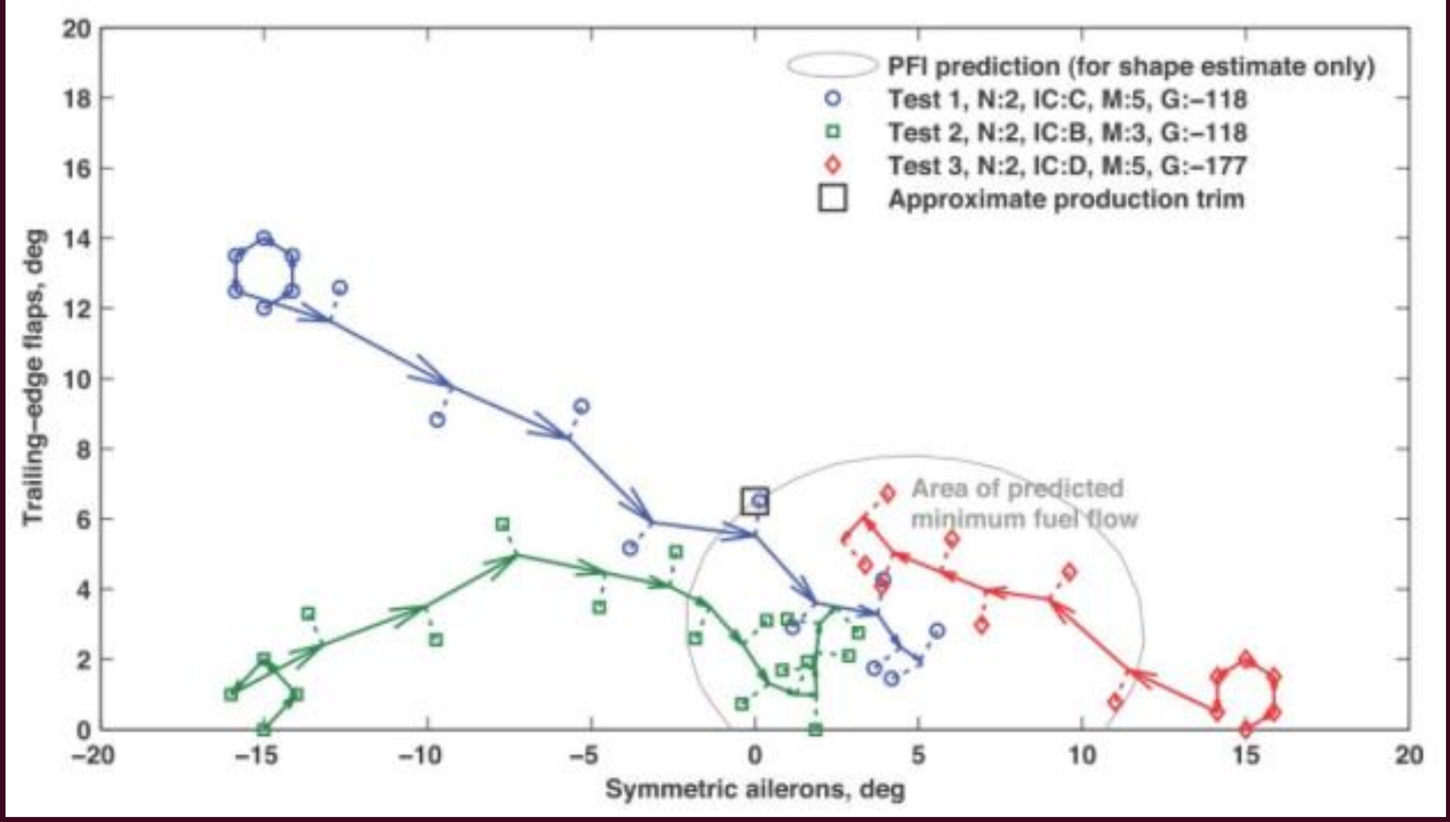
GUIDING PRINCIPLES

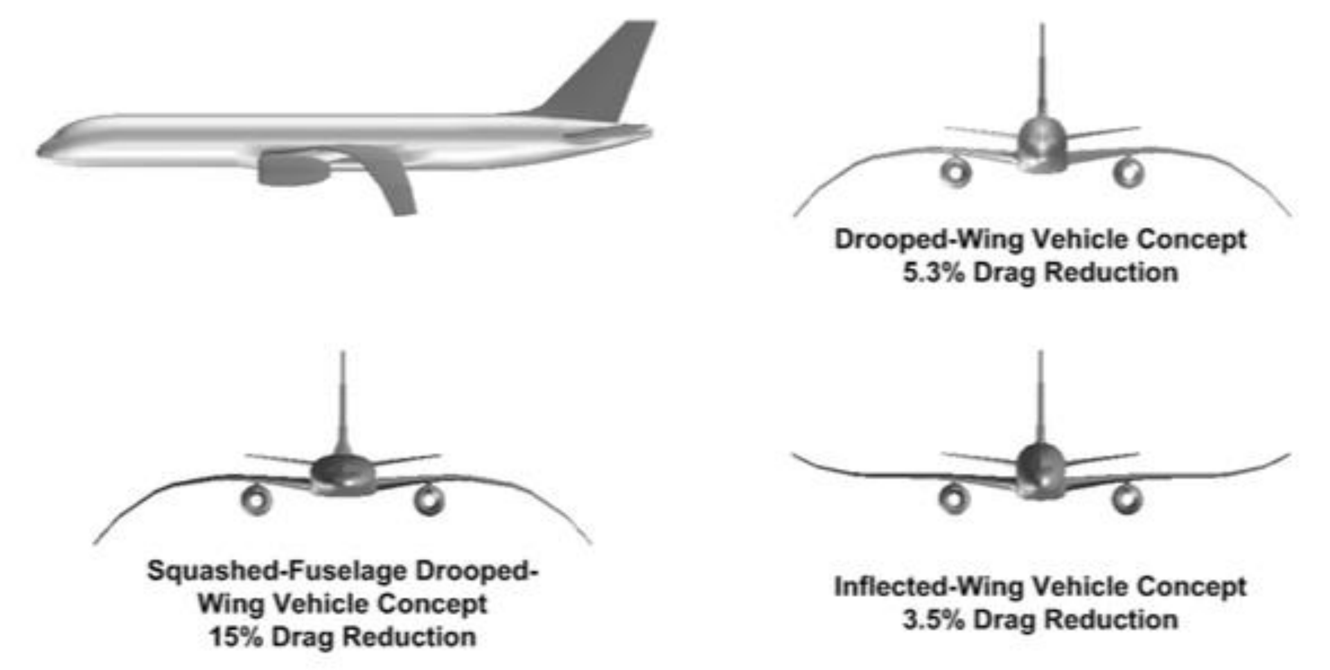
- Research through development, "…bring back the spirit of learning by flying" philosophy
  - Conduct flight testing early and often in the program, building on capabilities learned by previous tests
  - Validate design and analysis tools through flight test
- Everything will be open-source and published on the web
  - Resource for community to build on our success

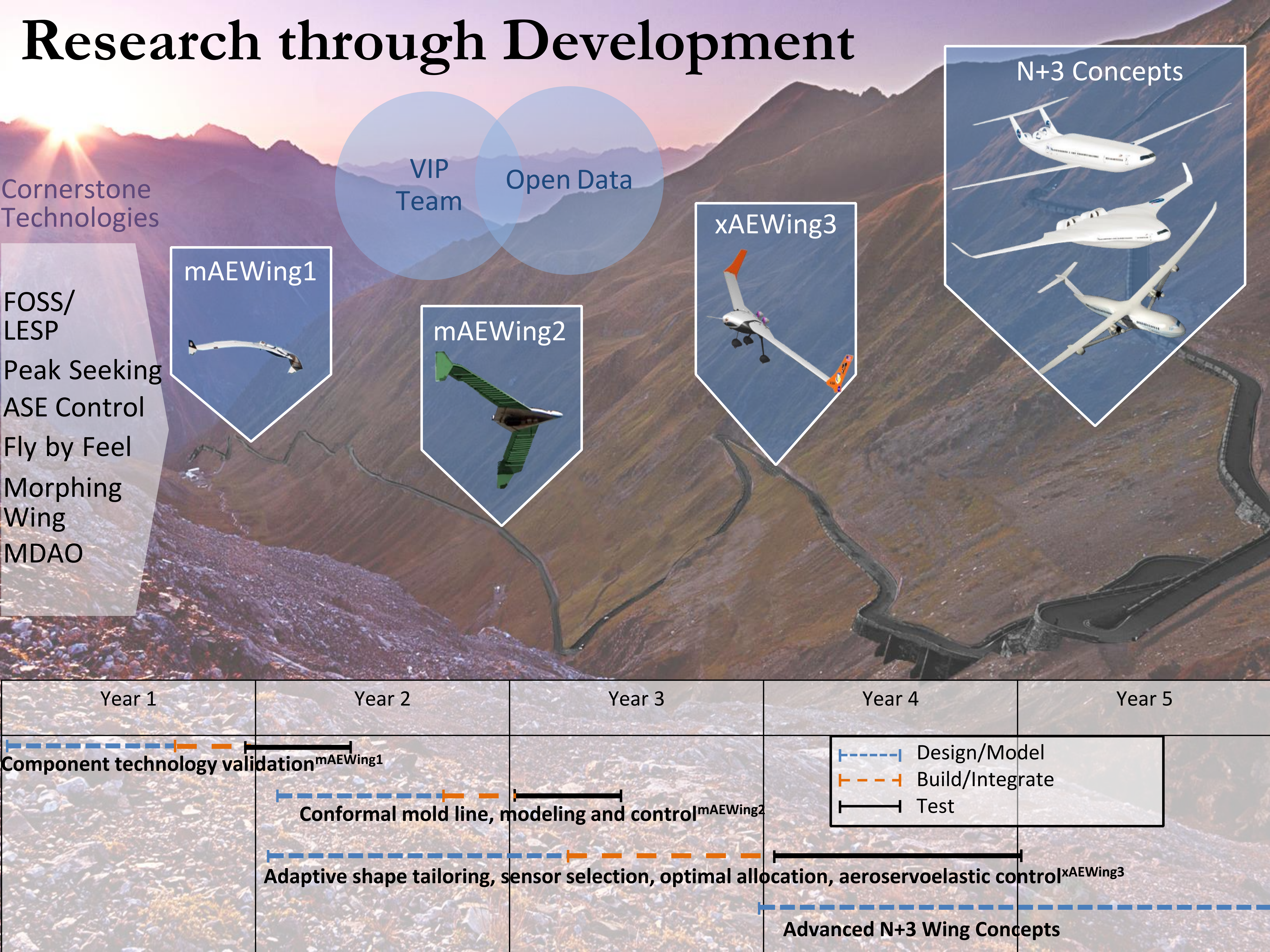


FOUNDATIONAL TECHNOLOGY

- Flutter suppression
- MDAO
- Coplanar multi-objective surfaces
- Conformal mold lines
- Optimal control allocation and load alleviation
- Shape Optimization
- Peak-seeking control laws
- FOSS
- LESP / Fly by Feel







Research through Development
VIP Team
Open Data
N+3 Concepts
Cornerstone Technologies
FOSS/ LESP
Peak Seeking
ASE Control
Fly by Feel
Morphing Wing
MDAO
mAEWing1
mAEWing2
xAEWing3
Year 1
Year 2
Year 3
Year 4
Year 5
Component technology validation mAEWing1
Conformal mold line, modeling and control mAEWing2
Adaptive shape tailoring, sensor selection, optimal allocation, aeroservoelastic control xAEWing3
Advanced N+3 Wing Concepts
Design/Model
Build/Integrate
Test

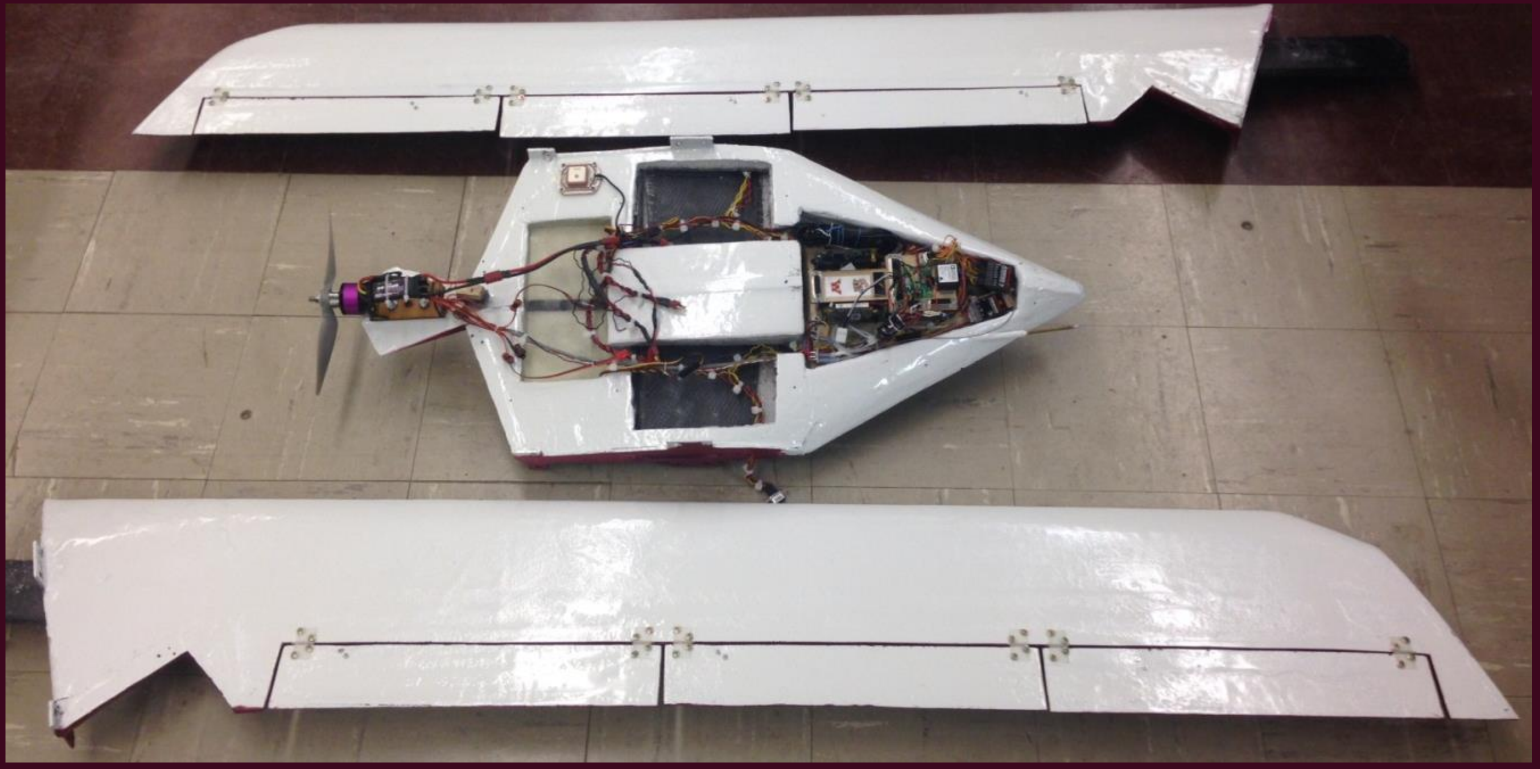
mAEWing1

- Put foundational technologies onto a single platform
- Demonstrate that some of them can work together
- Develop and refine models and control laws

➡ Flutter suppression, open-loop shape modification, and optimal control allocation with many discrete surfaces and traditional sensors

Design Overview

- Based on the Lockheed Martin Body Freedom Flutter (BFF) vehicle and the X-56A
  - Similar Outer Mold Line (OML) and control surface layout as the BFF
  - Removable wings similar to the X-56A
  - Programmatic risk reduction
    - Have linear models of the BFF
- Planning on only operating past first flutter mode
  - Enough to demonstrate flutter suppression and wing shape modification



Flight Envelope: Initial Tests

Test Point

100 ft AGL, 2500 ft length

On condition:
22 seconds at 65 knots
32 seconds at 45 knots
50 seconds at 30 knots

Launch

Landing

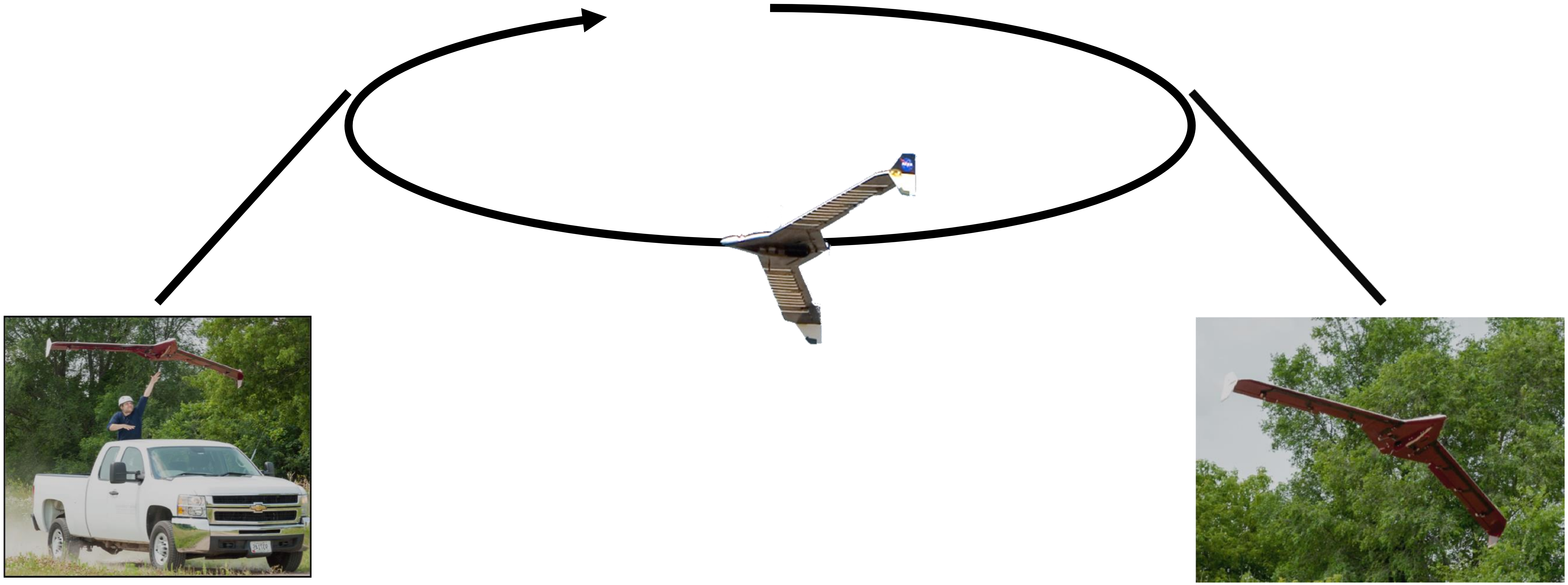
Flight Envelope: Final Tests

Multiple Test Points

400 ft AGL, 3200 ft straight line length

On condition 15 minutes:

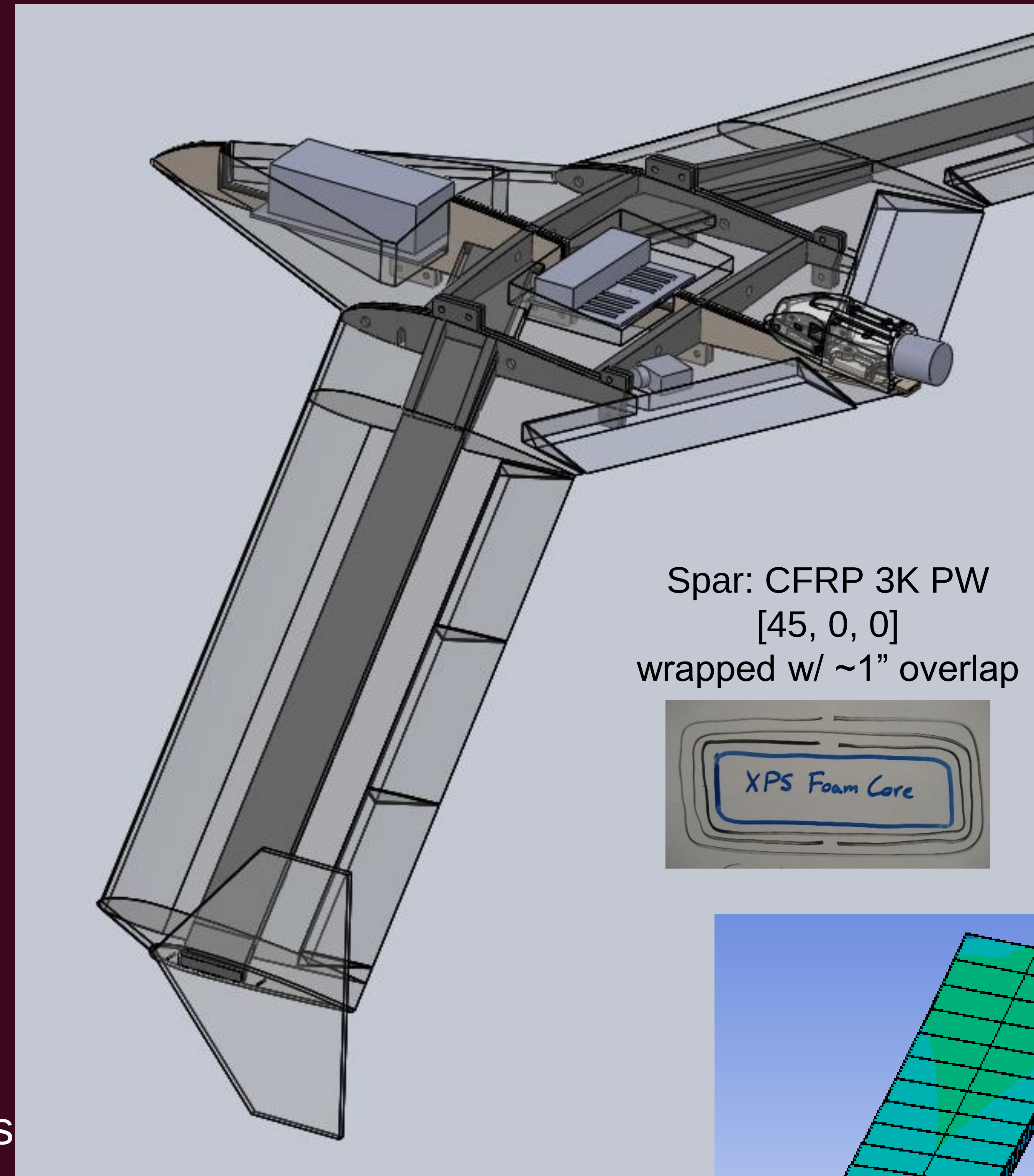
30 seconds at 65 knots   43 seconds at 45 knots   64 seconds at 30 knots



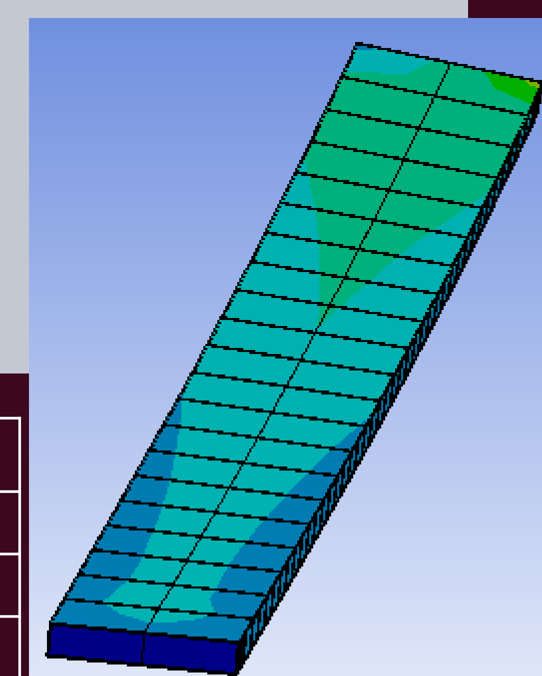
Launch   Landing

Airframe

- Structural concept follows the paradigm established by Lockheed's BFF airframe
  - Center body is designed to be rigid
  - Spar designed to carry wing load
    - Carbon fiber layup over foam core
  - Lightweight foam covered with fiberglass establishes the OML
- Initial flutter estimates
  - 1^{st} (BFF): 54 kts @ 4.4 Hz
  - 2^{nd}: 87 kts @ 12.3 Hz
- Prediction
  - Halpin-Tsai for composite properties
  - Euler-Bernoulli beam bending
  - St Venant beam torsion
  - Verification with Ansys and static test results



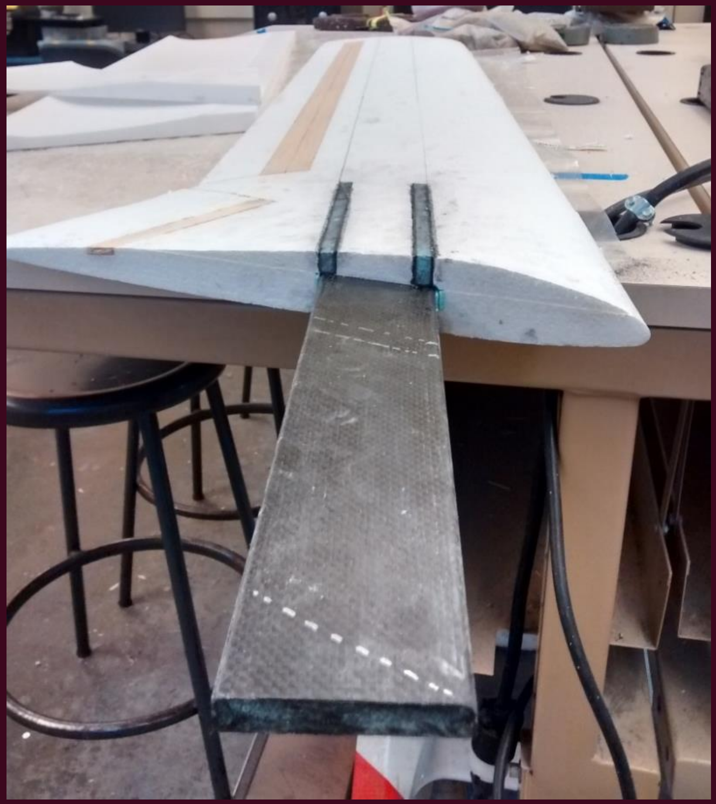
Spar: CFRP 3K PW
[45, 0, 0]
wrapped w/ ~1" overlap



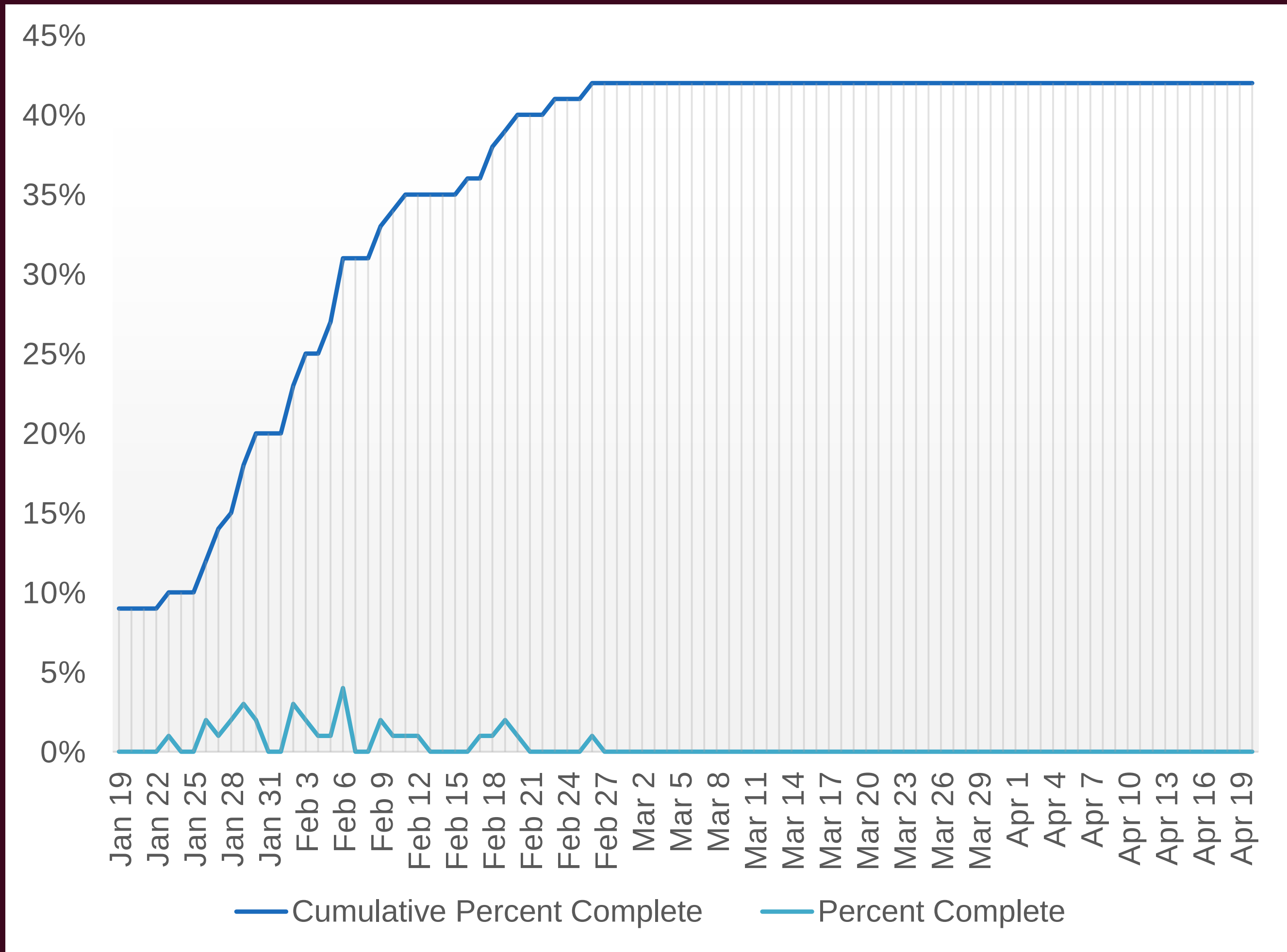
Spar Properties	EI (N-m^2)	E (GPa)	GJ (N-m^2)	G (GPa)
Target	98		56	
Predicted	97	46	59	8.6
Spar #5 (Right Wing)	109	50	82	**11.7**
Spar #6 (Left Wing)	106	49	74	**10.6**

Build Plan

- Integrated Build and Test Plan
  - Wing testing (Mass Property, Static, and Vibration) at three production stages
    - Spar only, Wing Form, and Finished Wing
    - Left and Right
  - Vibration test of Completed Airframe
- Current Status
  - Wing Design and Build Plans Complete
  - Centerbody Design 90%, Build Plan are conceptual
  - Fabrication/Assembly
    - 2 Spar Fabricated and Tested
    - Left Wing Form Fabricated and Tested
    - Left Wing Layup scheduled for Feb 27
  - Estimated Completion is April 20 (No buffer)
    - Greatest risk is getting PO for centerbody foam

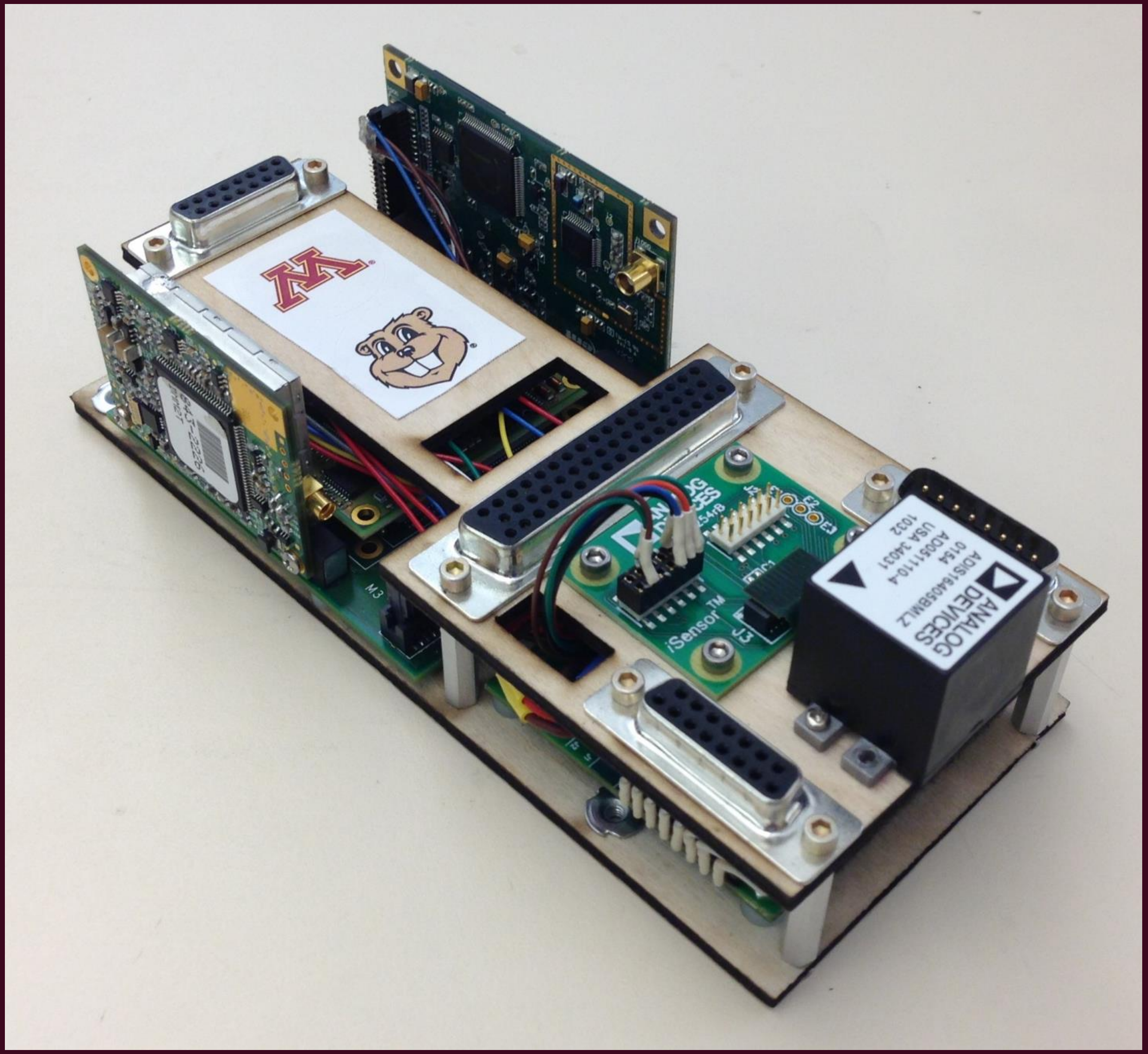


Left Wing Form
(shown 90% complete on Feb 23)



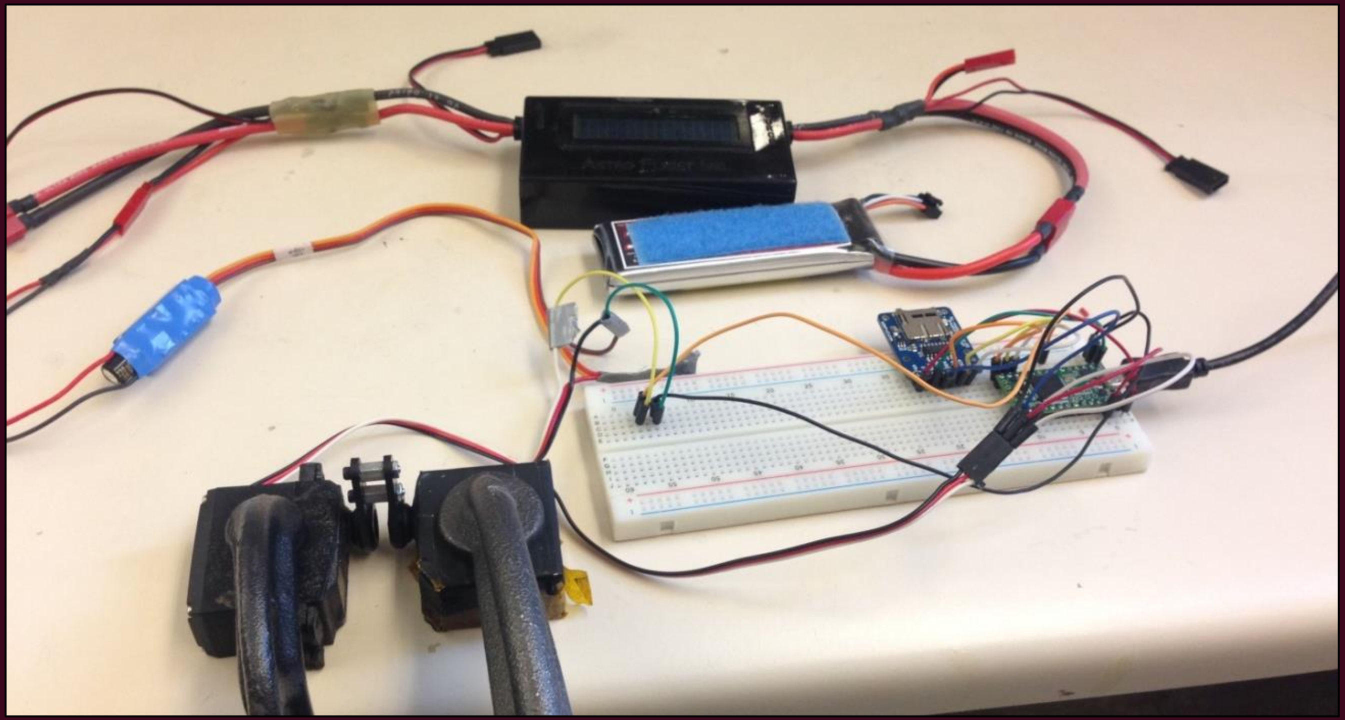
Systems: Goldy Flight Control System

- Open source, low cost flight control system
- Modular hardware and software
- IMU, GPS, telemetry and SOM computer
- Published CAD drawings, chip design files, wiring diagrams, and assembly manuals
- Lengthy flight legacy

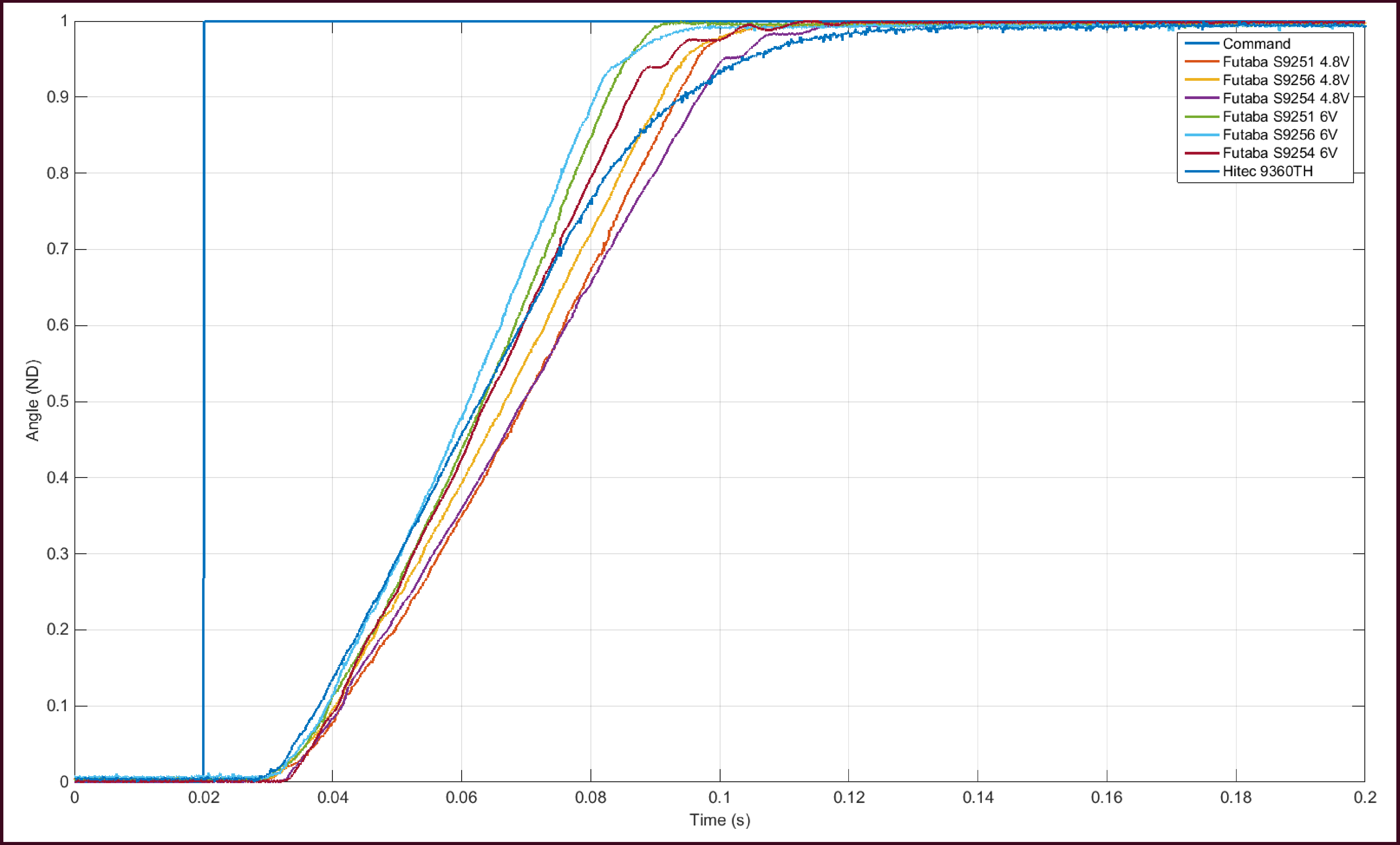


Systems: Actuators

- Conducted rate limit and bandwidth testing on BFF actuators as well as several actuators used in the UAV Laboratories and available on the market
- Found that the Futaba S9254 actuator has comparable performance as the BFF actuators and is easy to integrate into mAEWing1
  - Rate limit: 1270 deg/s
  - Bandwidth: 10.25 Hz

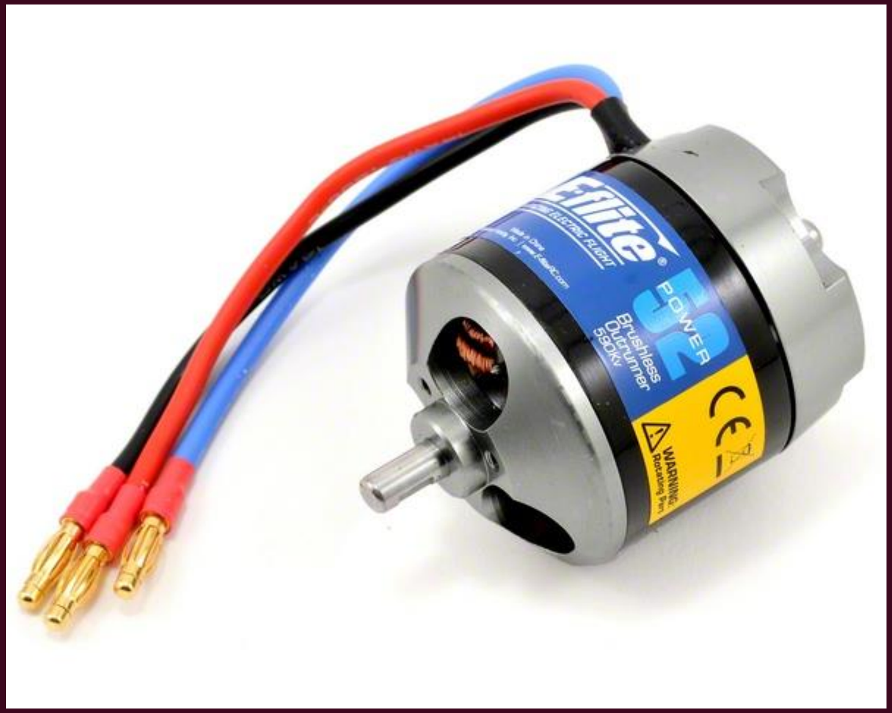


Systems: Actuator Rate Limit Testing

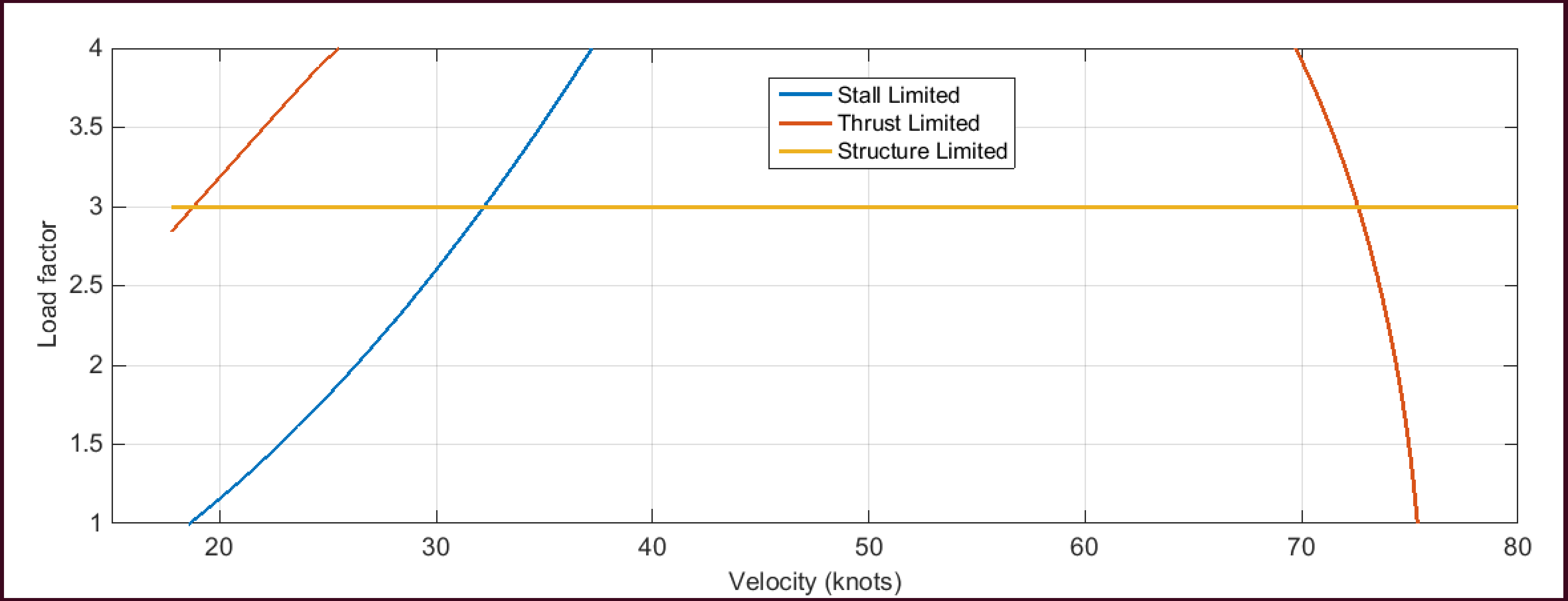


Systems: Motor and Propeller

- Back of the envelope aircraft performance estimates
  - Validated against flight test data on rigid vehicle
- Preliminary propulsion system design
  - Eflite Power 52 motor
  - Phoenix Edge Lite 75 ESC
  - 12x10 propeller
  - 6 cell battery
- Estimated maximum speed of 75 knots
  - Stall speed: 20 knots
  - Static thrust: 6.5 lbs
  - Thrust at 65 knots: 3.5 lbs

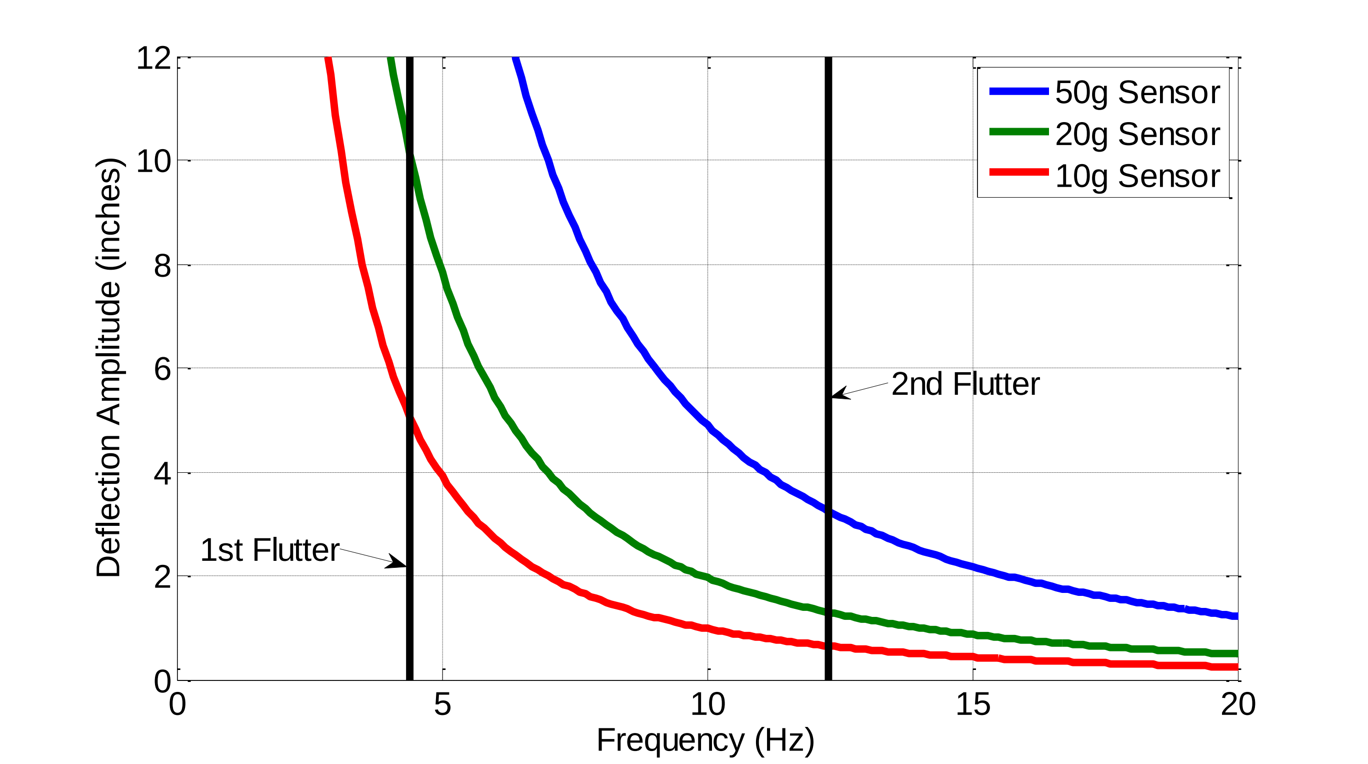


Estimated Performance

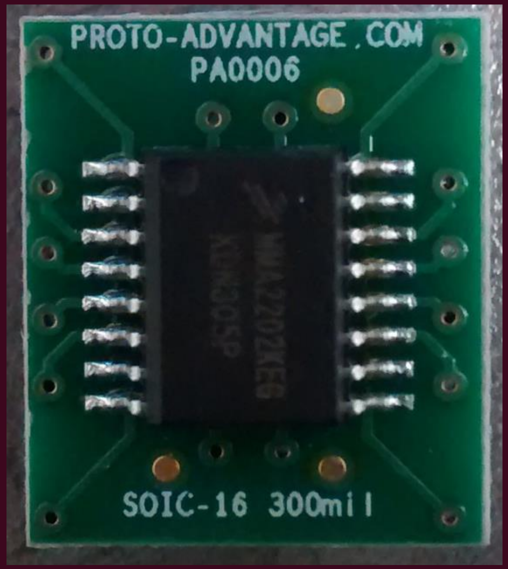


Systems: Accelerometers

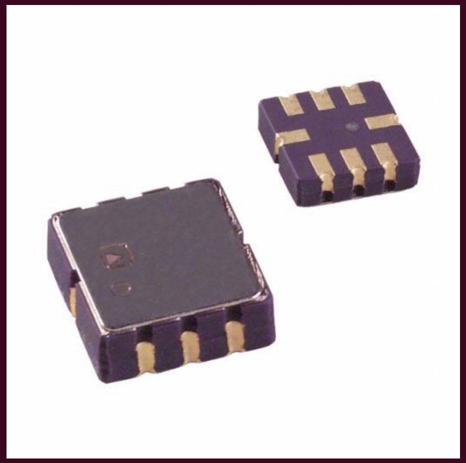
- Wing tip and center body accelerometers
  - Oriented for vertical sensitivity
  - 6 total – 2 per wing tip, 2 in center body
    - Placed in pairs at fore and aft locations
  - Range of interest
    - Sufficient to control 1st flutter mode
    - Detect onset of 2nd flutter mode
    - Static deflection is ~4 in/g



- Currently evaluating options
  - Currently have a +/-50g sensor that is being evaluated during component testing
    - Expecting poor sensitivity
    - Requires an anti-alias filter
  - Determining feasibility of using a +/-18g sensor
    - Improved sensitivity
    - External capacitors set an internal BW
    - Only available as surface mount

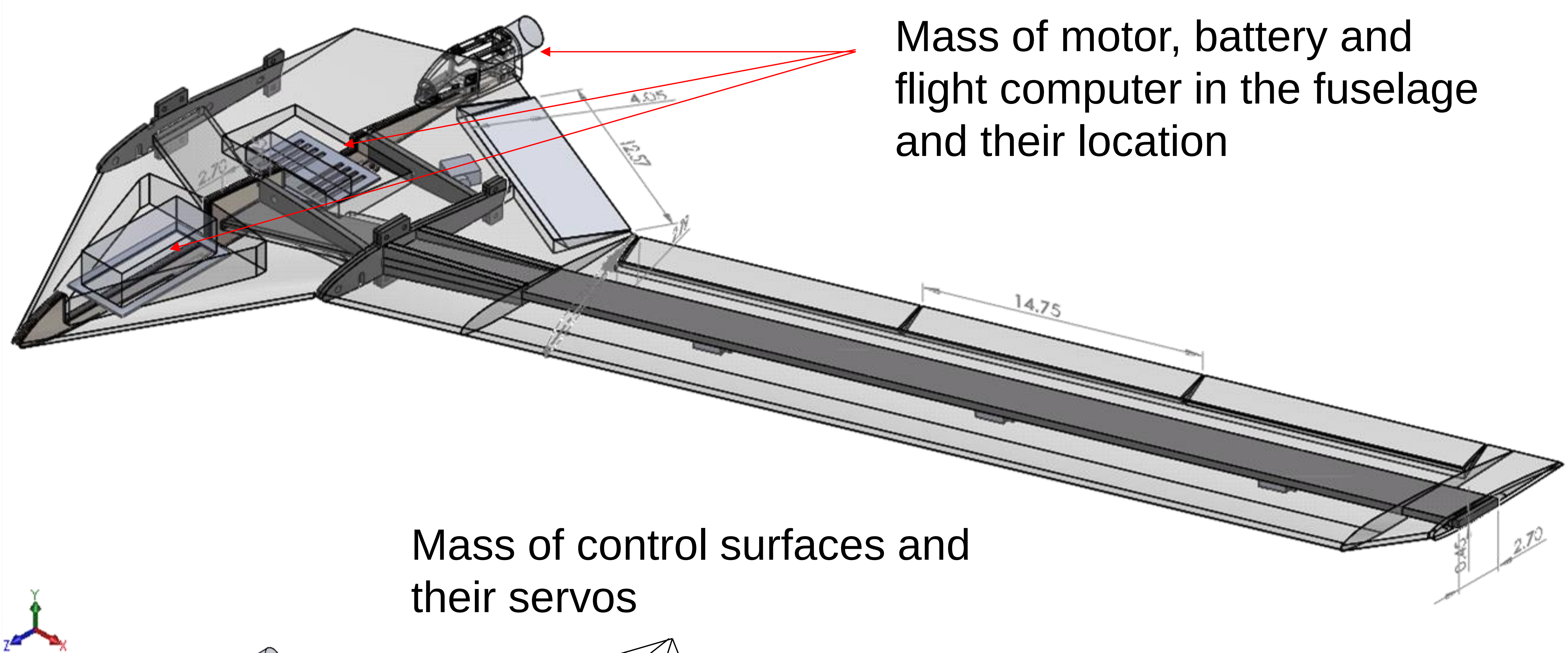


MMA2202KEG
Shown on breakout
1-axis, +/-50g



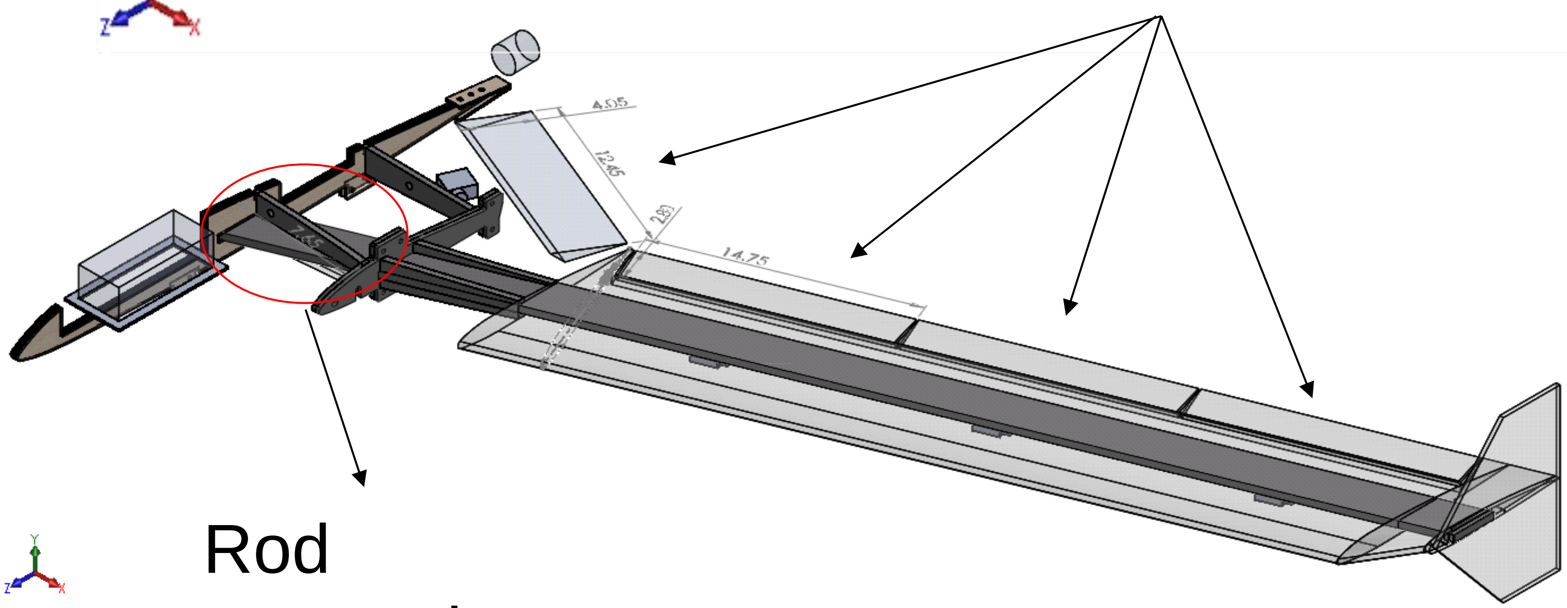
AD22035Z
2-axis, +/-18g

mAEWing1 Structural Model

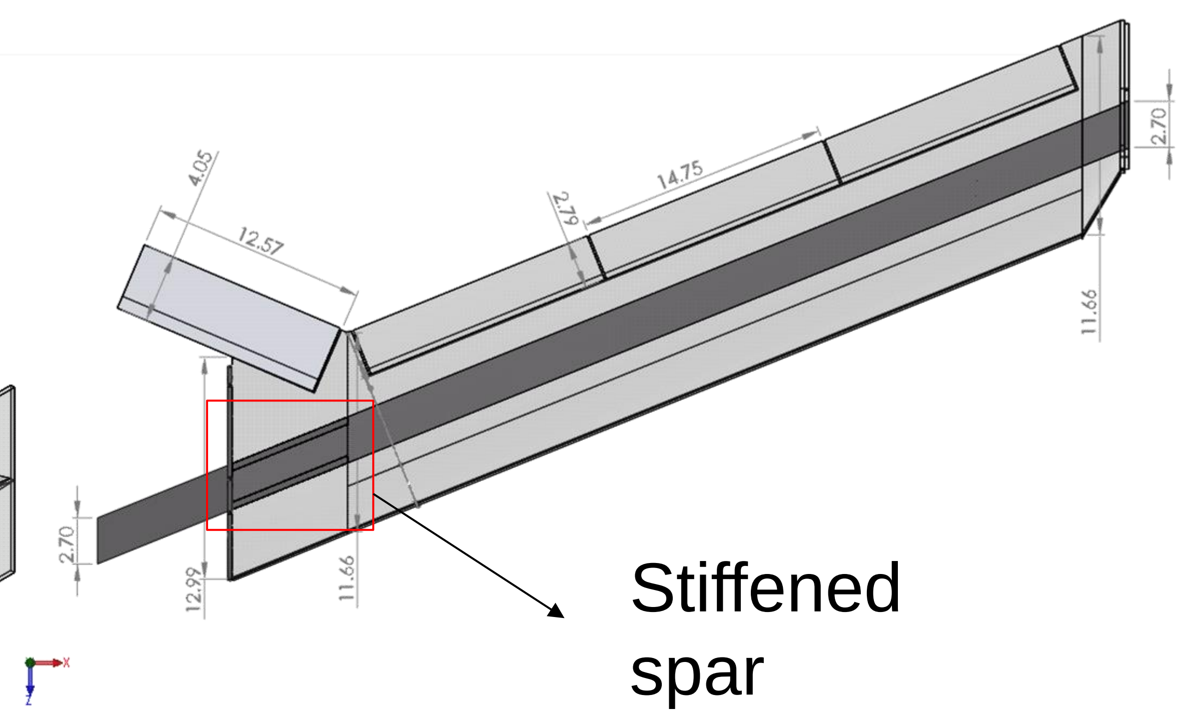


Mass of motor, battery and flight computer in the fuselage and their location

Mass of control surfaces and their servos



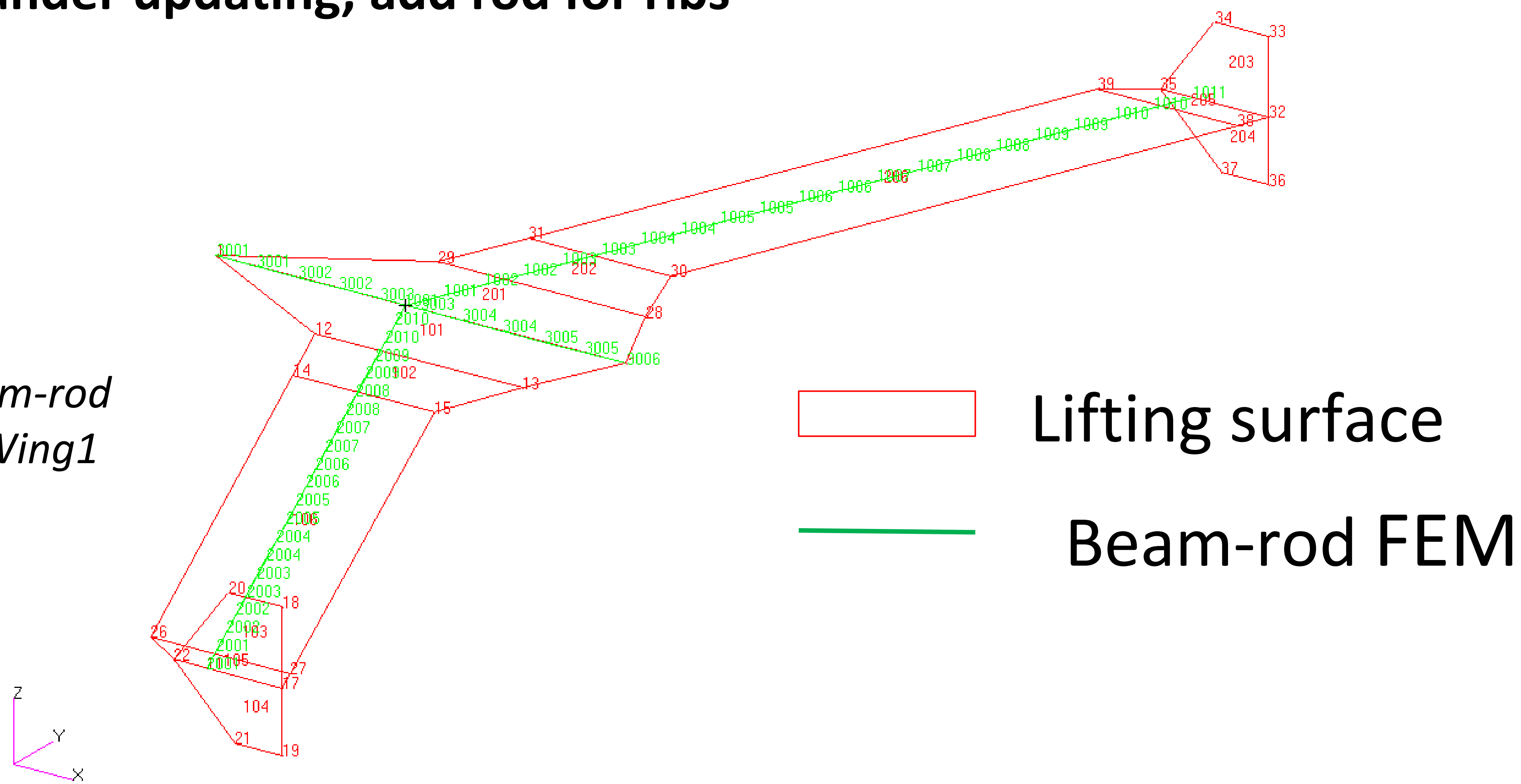
Rod connection



Stiffened spar

NASTRAN Beam-rod FEM of mAEWing1

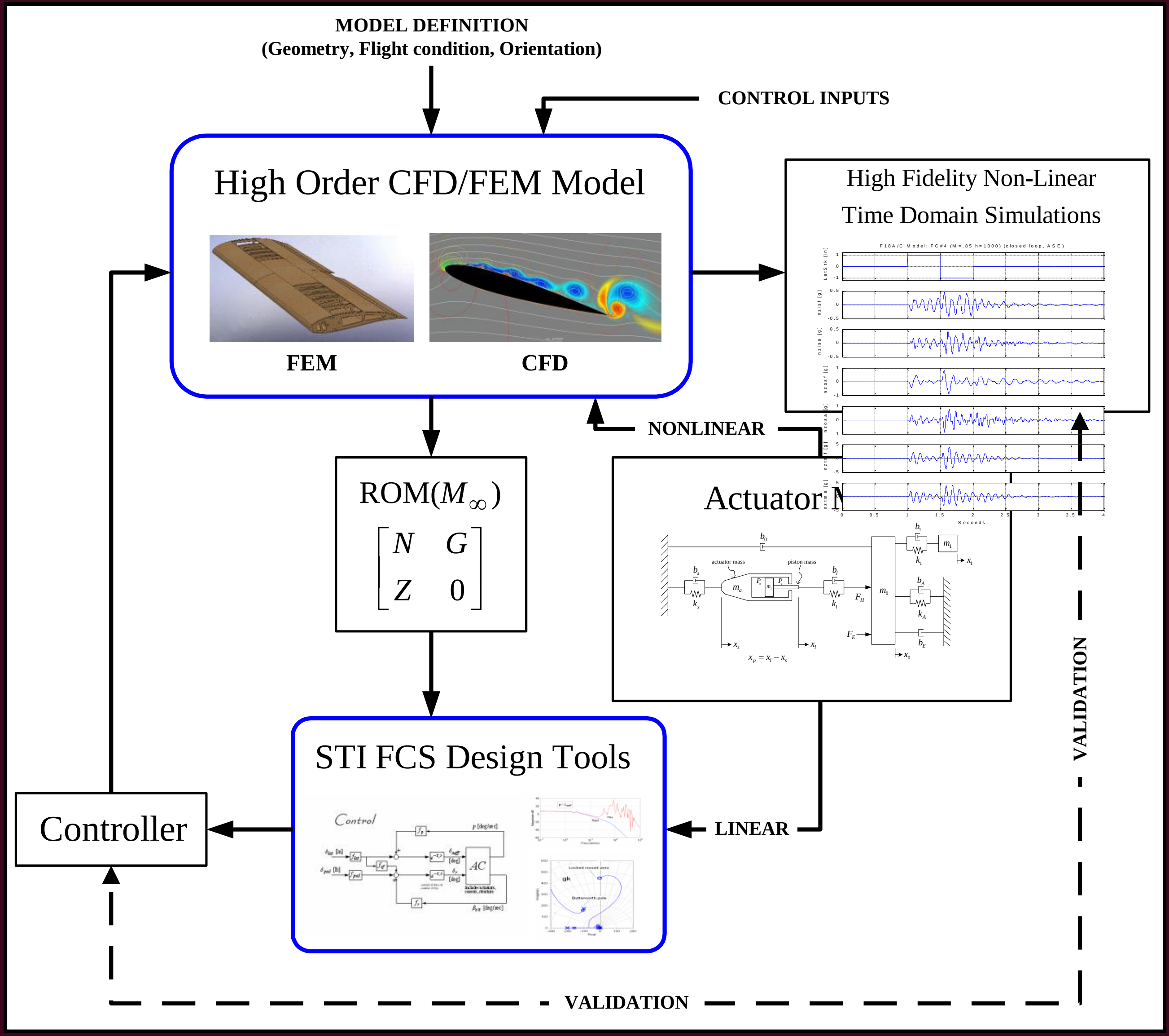
- **Timoshenko beam**
- **Composite spars with foam covered, use varied EI, GJ and GA to define beam properties.**
- **Lumped mass with I_{yy} to represent control surfaces and body flaps, and use stiff spring connection with main spars**
- **Lumped mass for instruments along fuselage and spars**
- **Model is under updating, add rod for ribs**



NASTRAN beam-rod FEM of mAEWing1

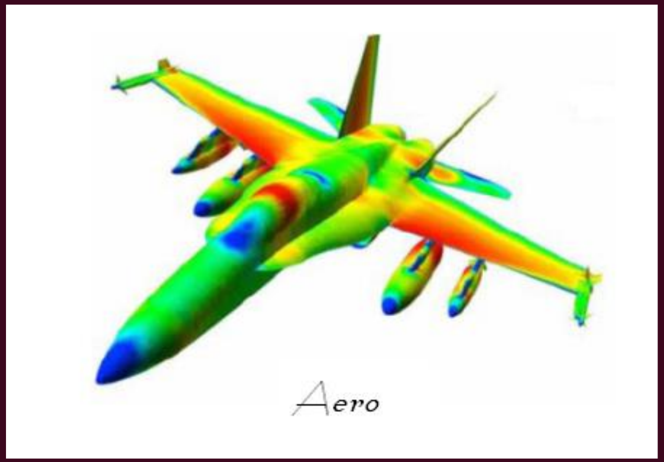
The CFD/CSD-based Modeling Approach

- A complete nonlinear full order model (NFOM) is represented in the CFD/CSD framework (millions of DOFs)
- Linear Reduced Order Models (ROMs) are created directly from the NFOM at fixed equilibrium flight conditions (hundreds of DOFs).
- Complete input-to-output state space models (IOROMs) are constructed using these ROMs and further information (sensor and effector location, etc.)
- FCS designed with IOROMs can be applied to the NFOM for enhanced validation

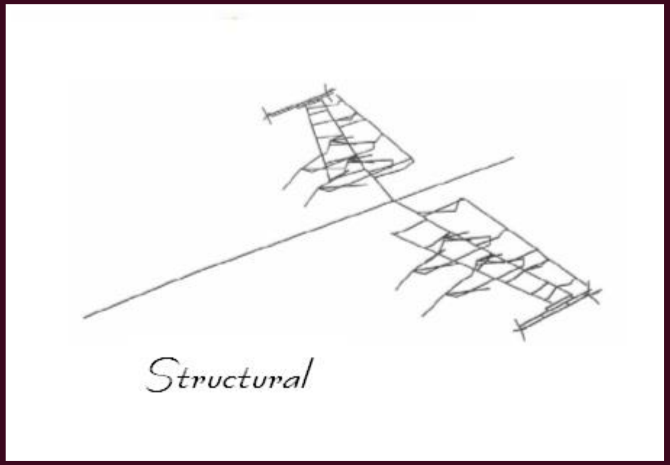


Significance

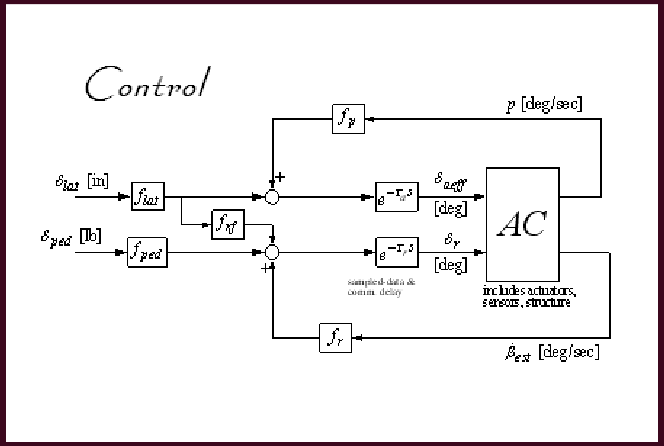
- A ***Universal ASE Model***:
  - Contains rigid body modes
  - Contains aeroelastic modes
  - Properly represents any coupling between rigid body and aeroelastic modes



- ***FCS design capability*** using a high-fidelity CFD/CSD model
  - Any flight regime
  - Leverages POD-based ROMs



- ***High-fidelity Simulation Capability*** with an active FCS:
  - Provides validation with a model of the highest capacity – viscous, transonic, nonlinear structure
  - Lays groundwork for a complete virtual flight test



The Linear Reduced Order Model (ROM)

- The Nonlinear Full Order Model (NFOM) requires parallel computing clusters for simulation
  - Takes on the order of ***several days*** to run simulations
  - Prohibitive for FCS design
- The ROM is a ***dramatically reduced*** approximation of the NFOM
  - Retains the essential dynamics, Ideal for system analysis to analyze dynamic behavior (i.e., eigenvalues). Ideal for FCS design
  - Takes seconds to run simulations
- The ROM technique employed by AERO utilizes ***Proper Orthogonal Decomposition*** (POD)
  - Linearize the governing equations about equilibrium non-dimensionally
  - Reduce order by defining a lower dimensional subspace via POD
  - Can be done in either the time or **frequency** domains.
  - Frequency domain approach boils down to choosing "snapshots," which are a function of shape and frequency.
  - ROM construction is computationally intensive but the ROM can be utilized for subsequent analysis and simulations very rapidly.

ROM Details

- Governing Equations (ALE):

$$\left(A(x)w\right)_{,t} + F(w, x, \dot{x}) = 0$$ [fluid]

$$M\ddot{u} + f^{\text{int}}(u, \dot{u}) = f^{ext}(u, w)$$ [structure]

$$\tilde{K}x = \tilde{K}_c u$$ [grid deformation]

- Fluid ROM:

$$\dot{w}_r = -Hw_r \qquad H(p_\infty, \rho_\infty) = \tilde{H}\sqrt{p_\infty / \rho_\infty}$$

- Aeroelastic ROM:

$$\dot{w}_r + Hw_r + B\dot{u}_m + Cu_m = 0$$
$$I_m \ddot{u}_m + \Omega^2 u_m = Pw_r$$

$$\begin{bmatrix} \dot{w}_r \\ \ddot{u}_m \\ \dot{u}_m \end{bmatrix} = \begin{bmatrix} -H & -B & -C \\ P & 0 & \Omega^2 \\ 0 & I & 0 \end{bmatrix} \begin{bmatrix} w_r \\ \dot{u}_m \\ u_m \end{bmatrix}$$

The Complete IOROM

$$\dot{q} = Nq + GF_i$$

$$y_s = Zq + DF_i$$

$$F_i \longrightarrow \boxed{ASE(M_\infty, p_\infty, \rho_\infty)} \longrightarrow y_s$$

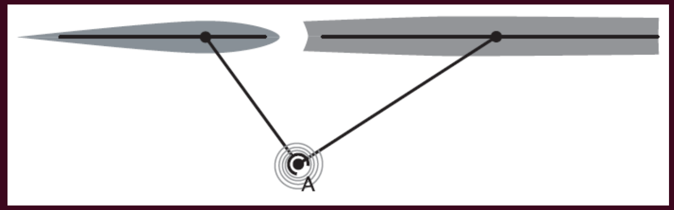
q **– aeroelastic state vector**

F_i **– Input hinge moments**

y_s **– output sensors**

$$q = \begin{bmatrix} w \\ \dot{u}_m \\ u_m \end{bmatrix}$$

- In general, constructed by defining input and output nodes and mapping from global to modal coordinates.
- Describes, in entirety, the complete input/output relationship.
- System matrices (*N*, *G*, *Z*, *D*) are based on a fixed constant Mach number and orientation and are a function of atmospheric density (ρ_∞) and pressure (p_∞), or alternatively altitude (*h*). *N* is the POD-based ROM from AERO.
- This system is ideal for linear system analysis and ***FCS design***.
- System stability is determined from eig(N). flutter points as a function of p_∞, ρ_∞ or *h* can be found.



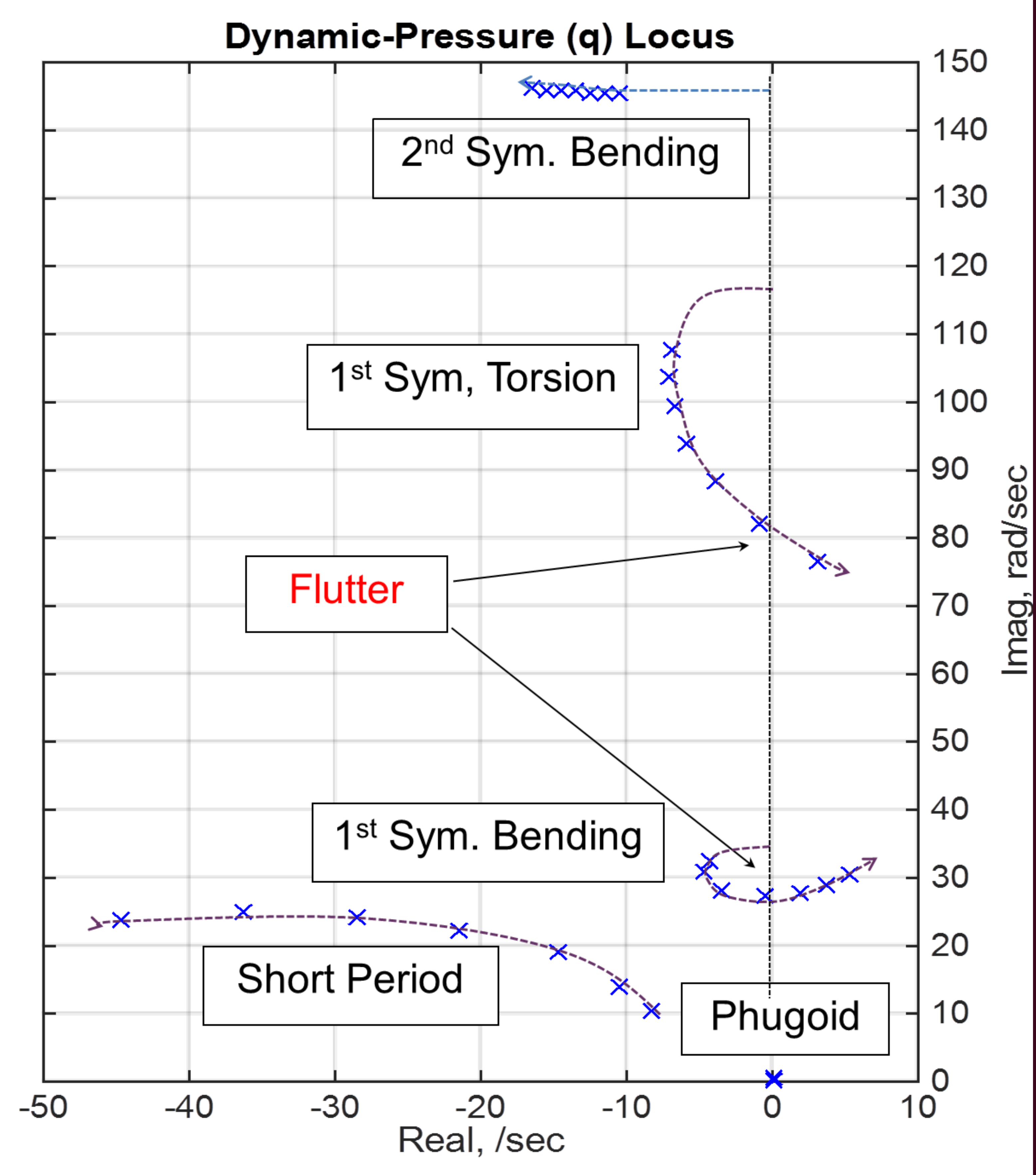
The “Flight-Dynamics” Modeling Approach

- Based on mean-axis formulation of Milne (1964)* Axes of undeformed vehicle.
- Yields full 6 + nDOF EOMs
- EOMs expressed in “body-fixed” vs inertial axes and expressed in terms of aero coefficients - Typical of flight-dynamics models of rigid vehicles.
- Non-linear EOMs for rigid-body DOFs. Linear EOMs for elastic DOFs

  e.g., real-time, piloted simulations**
- Linearized models for CLAW design and analysis
- Uses FEM solution for shape functions – Rayleigh-Ritz
- Various aerodynamic modeling approaches – wind tunnel, slender-wing, VLM, DLM
- Has been applied to develop longitudinal model of LM’s BFF vehicle.

* Milne, “Dynamics of the Deformable Airplane,” UK Ministry of Aviation, Aero Res Council Rept. 1964.
** Schmidt, et al, "A Simulation Study of the Flight Dynamics of Elastic Aircraft," NASA CR 4102, 1987.
** Raney,et al, “ Impact of Structural Vibration on Flying Qualities of HSCT,” AIAA AFM 2001- 4006.

Flutter Analysis - q Locus



BFF Vehicle
Longitudinal Dynamics
Sea Level

Two flutter conditions

BFF and BT flutter

BFF $V_{flutter}$ = 47 kt.

BT $V_{flutter}$ = 57 kt.

BFF genesis mode –
1st symmetric bending

BT genesis mode –
1st symmetric torsion

Comparison With LM Results*

Model/Test	BFF Flutter Speed	BFF Flutter Frequency	BT Flutter Speed	BT Flutter Frequency
LM Analytical	43 kt	4.2 Hz	57 kt	10.5 Hz
LM Flight Test	46 kt	4.5 Hz	NA	NA
FD Model	47 kt	4.4 Hz	57 kt	12.7 Hz

- Captured both flutter modes
- Matched genesis flutter modes
- Matched flutter speeds – BFF critical
- Matched BFF Flutter frequency

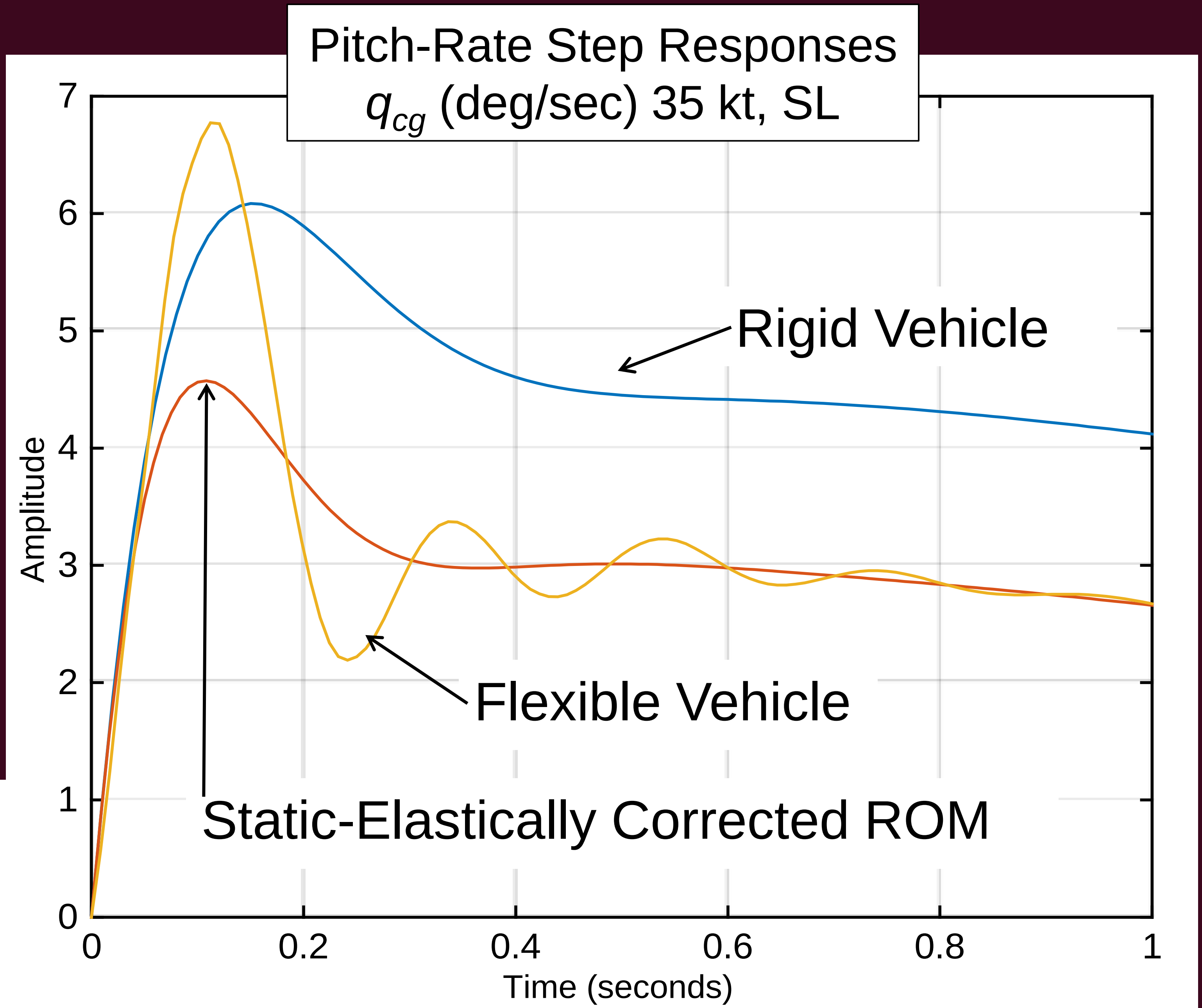
- Burnett, Edward L., et al, " NDOF Simulation Model for Flight Control Development with Flight Test Correlation," Lockheed Martin Aeronautics Co., AIAA Modeling and Simulation Tech. Conf., 2010-7780, 2010.

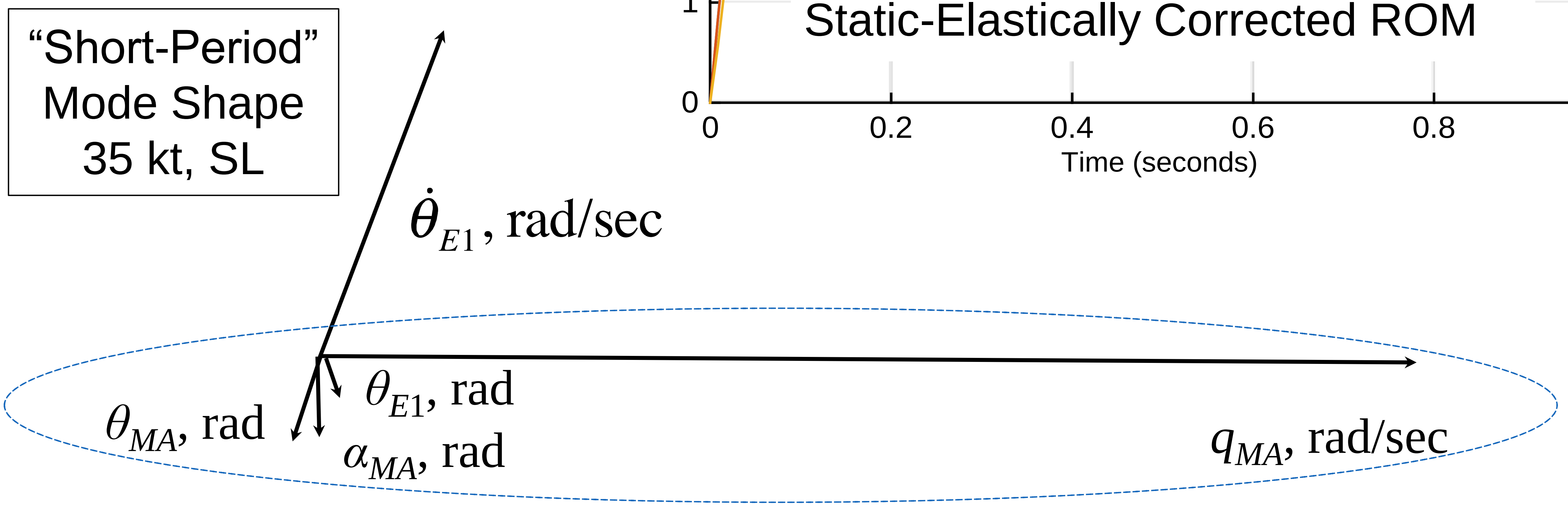
BFF Vehicle Pitch-Attitude Dynamics

No classical short-period mode
"RB-pitch-dominant mode"

Pitch attitude highly coupled with aeroelastic response (1^{st} bending/tors. vibr. mode)

Body-Freedom-Flutter mechanism

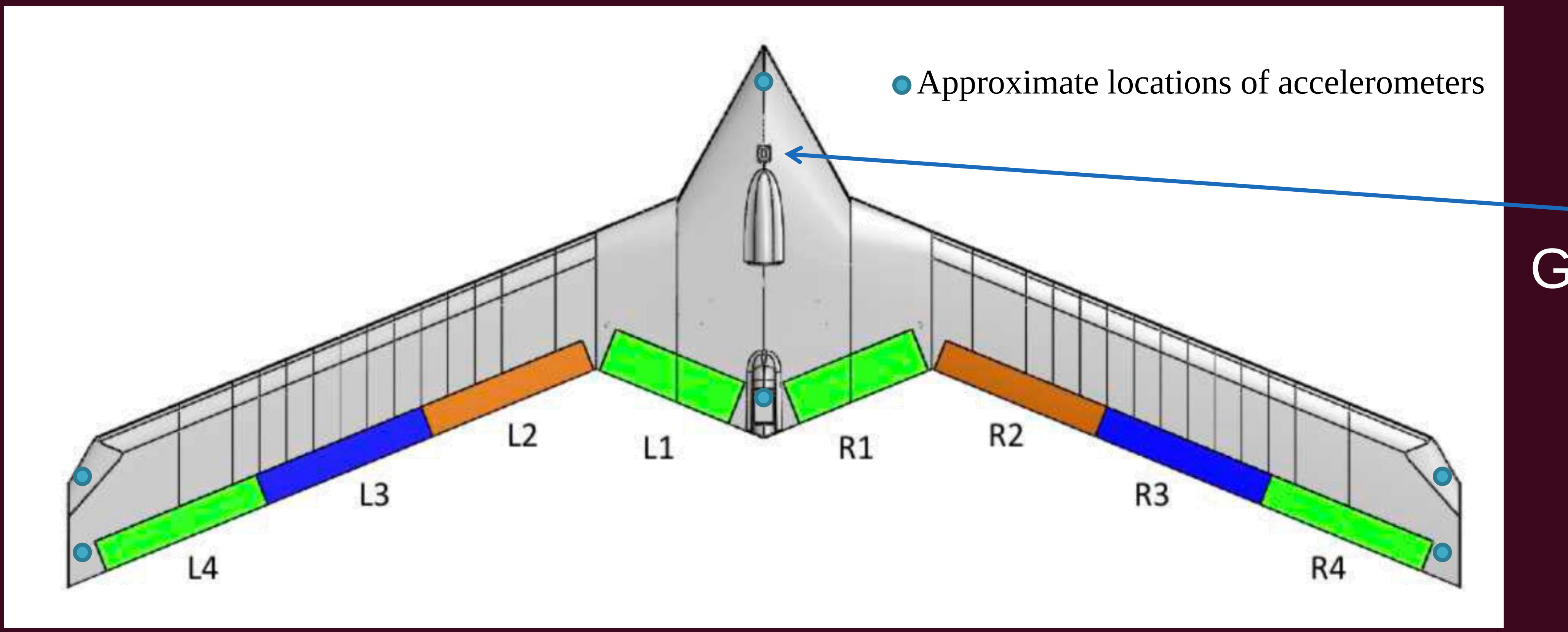




Flight Control: Active Flutter Suppression

- Active Flutter Suppression (AFS) required on mAEWing1 vehicle
- Investigated AFS on existing Lockheed Martin BFF Vehicle
- Develop and validate tools and techniques
- Three AFS approaches considered
    1. Conventional Frequency Domain Method – ILAF (DKS)
    2. MIMO Methods - MIDAAS (STI), LPV (UMN)

BFF Vehicle Sensors and Surfaces



Body Flaps L1 – R1

Aileron L2 – R2

Elevator L3 – R3

Flutter Supp. L4 – R4

Conventional Control Law Design: ILAF

- Seek an integrated approach to active flutter suppression and longitudinal stability augmentation
- Seek robustness against changes in mass distribution and/or stiffness properties

- One approach - concept of ILAF (Wykes*)

  "Identically Located Acceleration and Force"

- ILAF – "A force applied to a structure proportional to the velocity of the structure measured at the point of application of the force will increase the damping of all structural modes."

- Requires no knowledge of the vibration mode shapes – robust

  If can implement true ILAF – point force.

- Used to design active-structural-mode-control system on B-1

- Wykes, et al, "Design and Development of a Structural Mode Control System," NASA CR-143846, Rockwell Int.., 1977.

ILAF Applied to BFF Vehicle

Sensor-Actuator Selection

- Leverage insight into vehicle’s dynamics
- BFF condition - interactions between the vehicle pitch-dominant

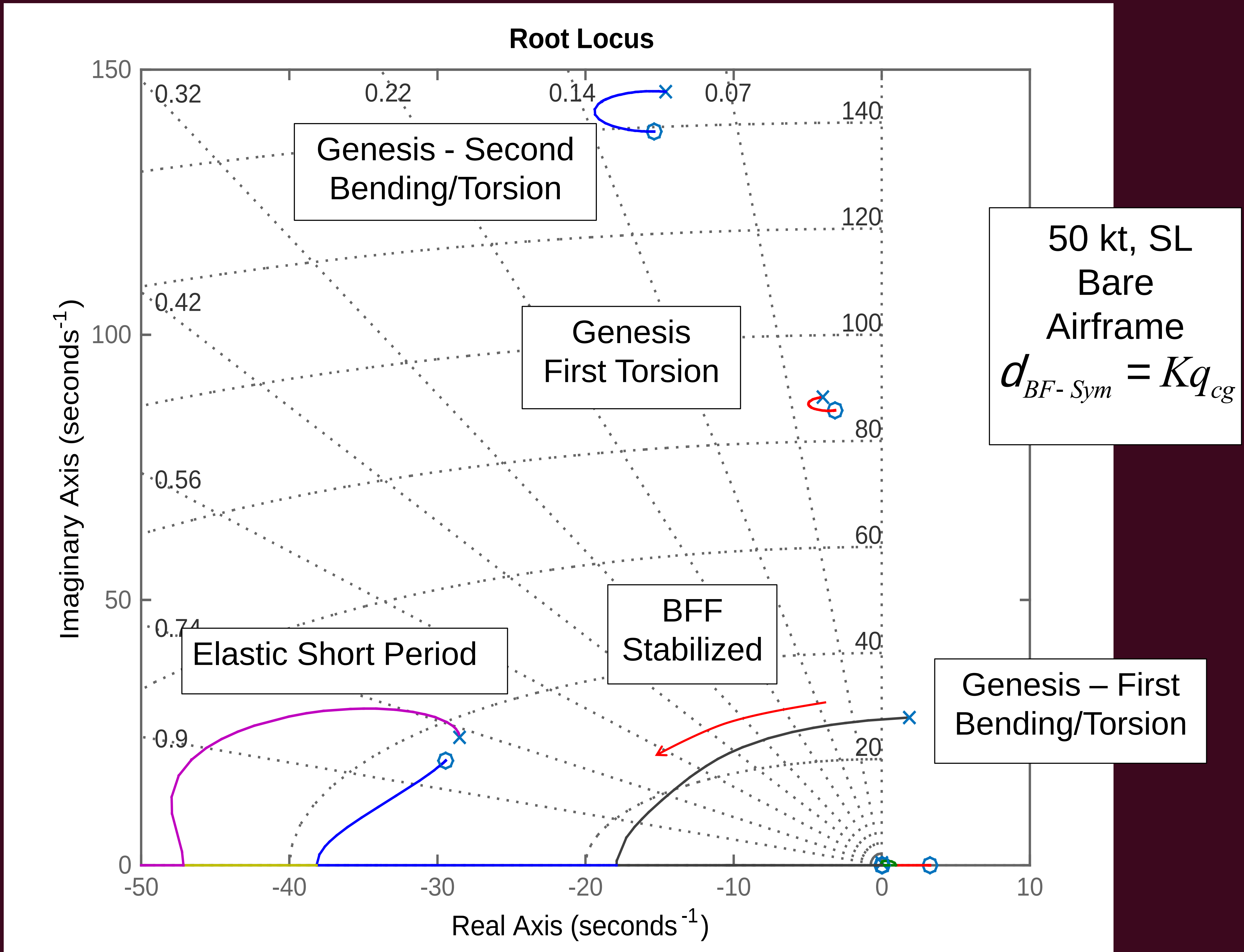
  mode (elastic-short-period) and the first aeroelastic mode
- First aeroelastic involves both bending, center-body pitching, and wing twist.
- “Rigid-body” pitching replaces wing twist in the conventional bending-torsion flutter mechanism.
- Second flutter mode is more classical bending-torsion – max at wing tips
- Corollaries to ILAF:

  1) Apply pitching moment to location on the structure proportional to pitch rate measured at the same location.

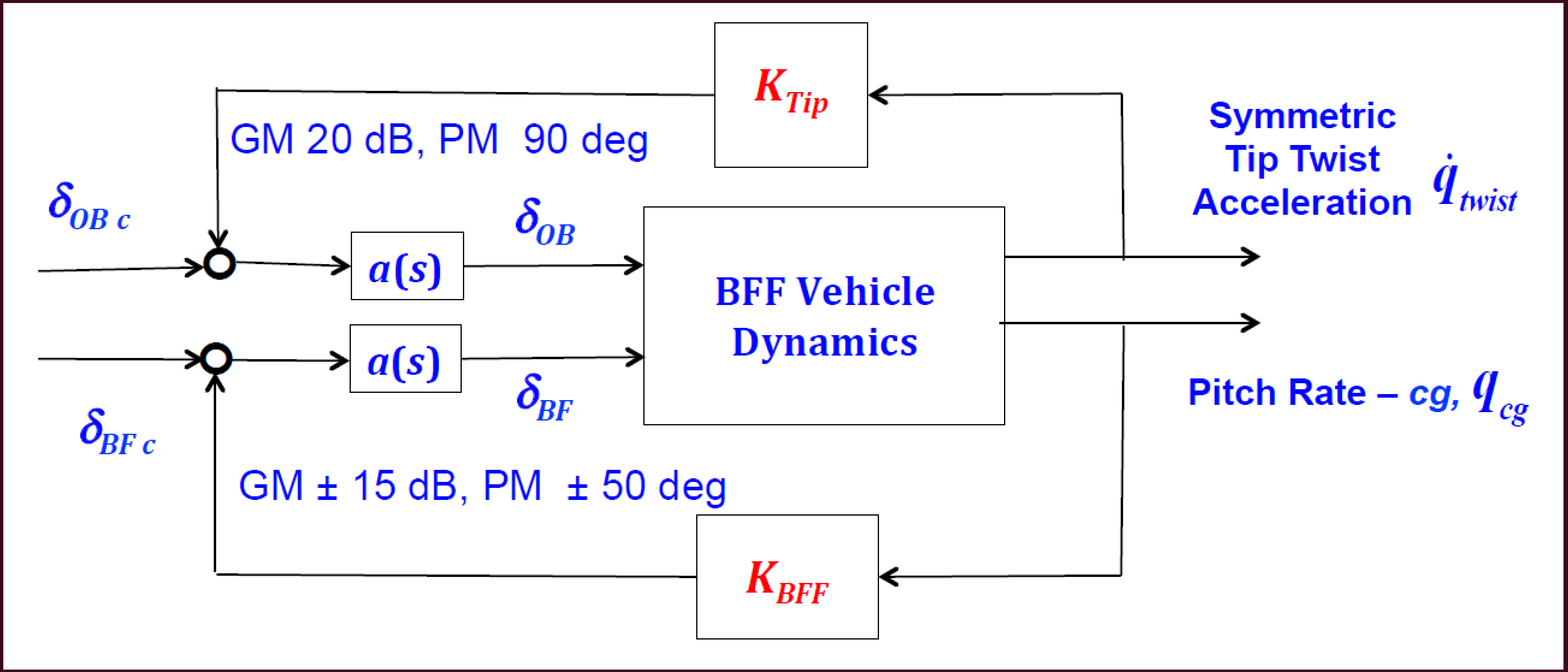
  2) Apply wing torque at tips proportional to wing-tip twist.
- Approximate ILAF: feedback center-body pitch rate to body flaps
  and feedback wing-tip twist to outboard flaps

Gain Root Locus: BFF Stabilized

Pitch Rate to Body Flap



Control Law Architecture: ILAF Option

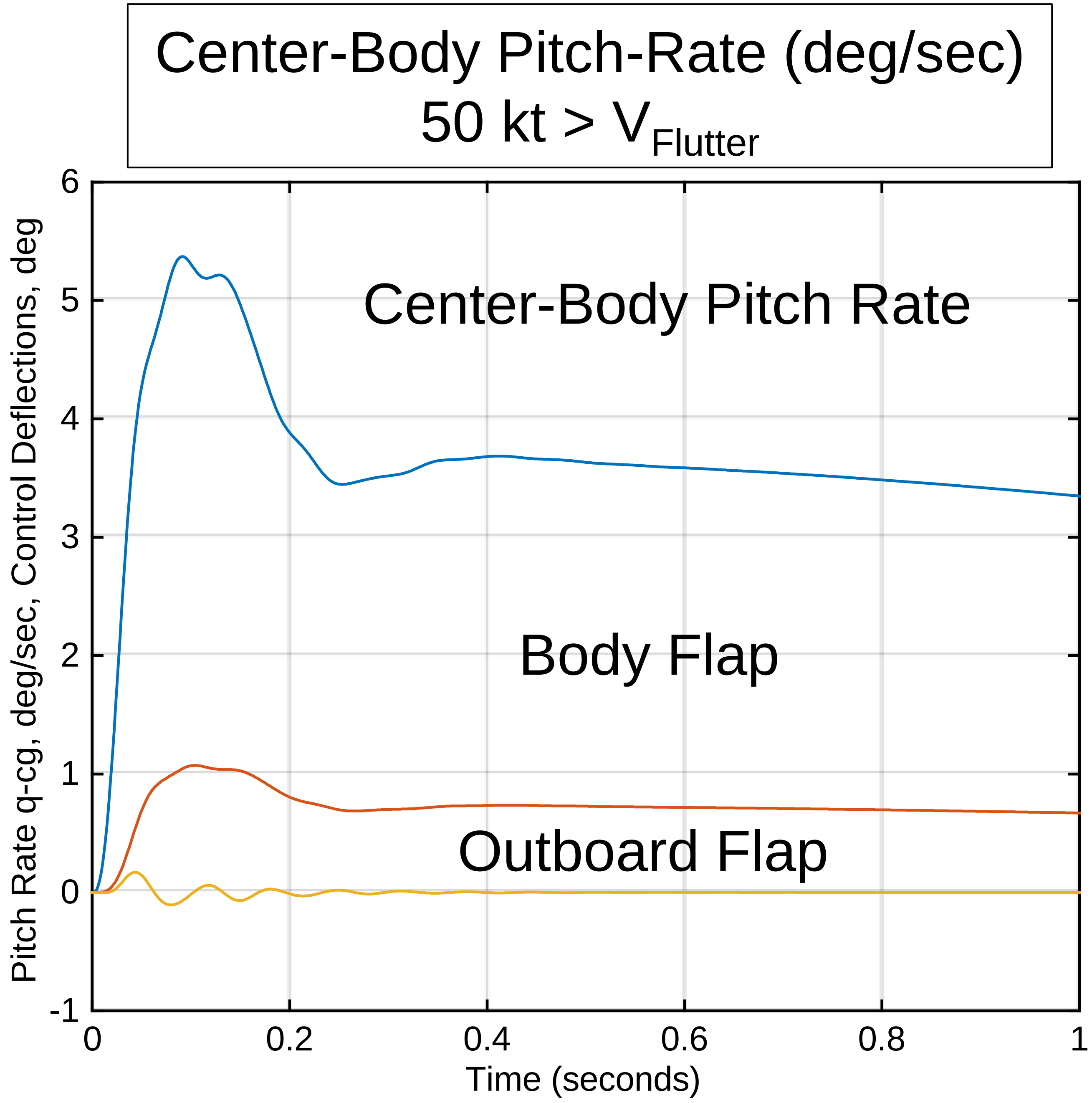


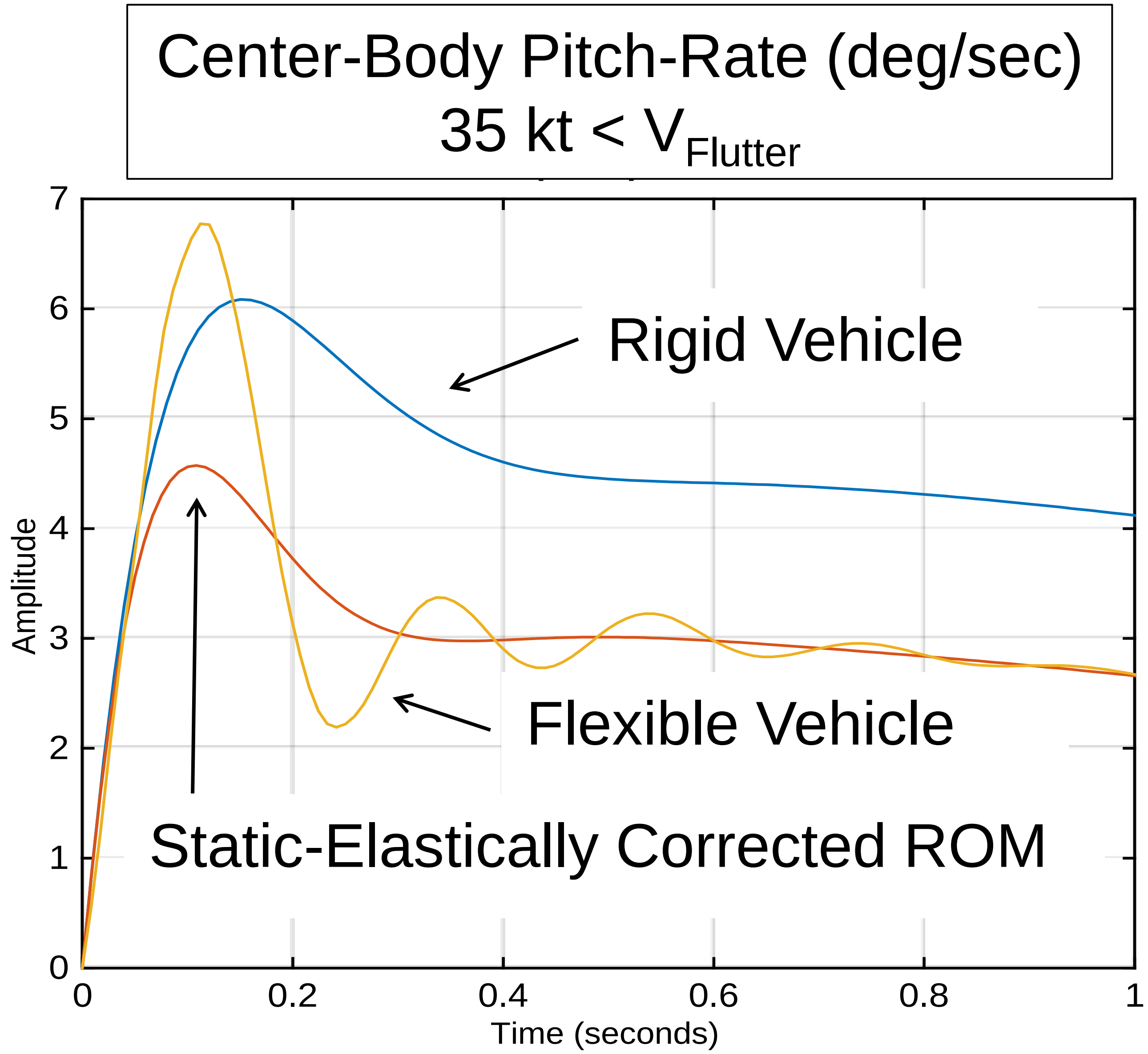
Center-body pitch rate to symmetric body flap – K_{BFF} ~ 0.2 deg/deg/sec

Symmetric blended accelerometer to symmetric outboard flap
- K_{Tip} ~ 0.0005 deg/deg/sec^2

Notes: Second flutter mode (torsion) suppression is actuator limited at 60 kts
Washout and low-pass filters also being considered

Closed Loop Pitch-Rate Step Responses





ILAF AFS/SAS Summary

- Stabilizes both BFF and BT flutter modes, at both 50 and 60 kt.
- Reasonable margins achieved in all cases (> ± 12 dB, > ± 40 deg)

  Including effects of actuator bandwidth and phase loss.
- Simple, two-loop, constant-gain architecture with sensor blending.
- Reasonable pitch responses – similar to that for stable vehicle < VFlutter
- Modest control-surface demands

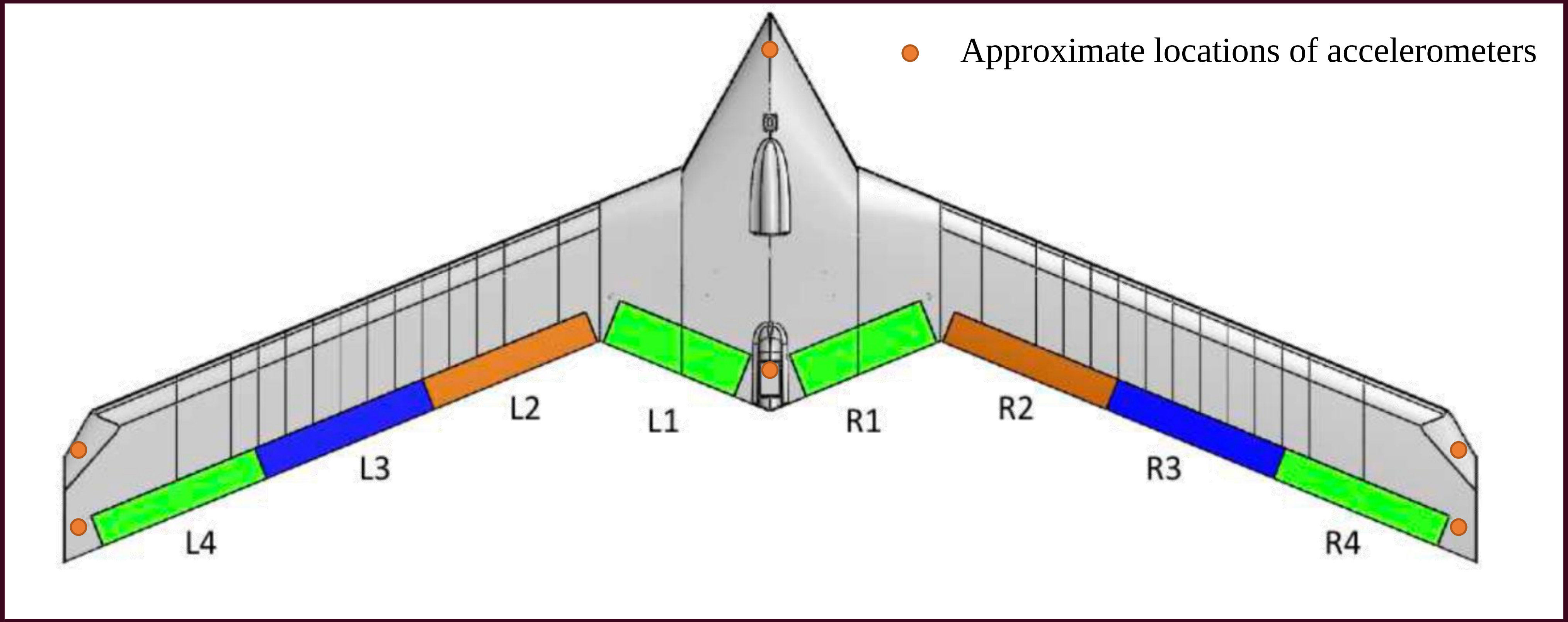
Schmidt, "Integrated Stability Augmentation and Active Body-Freedom-Flutter Suppression For a Flexible Flying-Wing Research Drone," DKS PAAW Working Paper, January, 2015. To be submitted for publication.

Flutter Suppression using MIDAAS

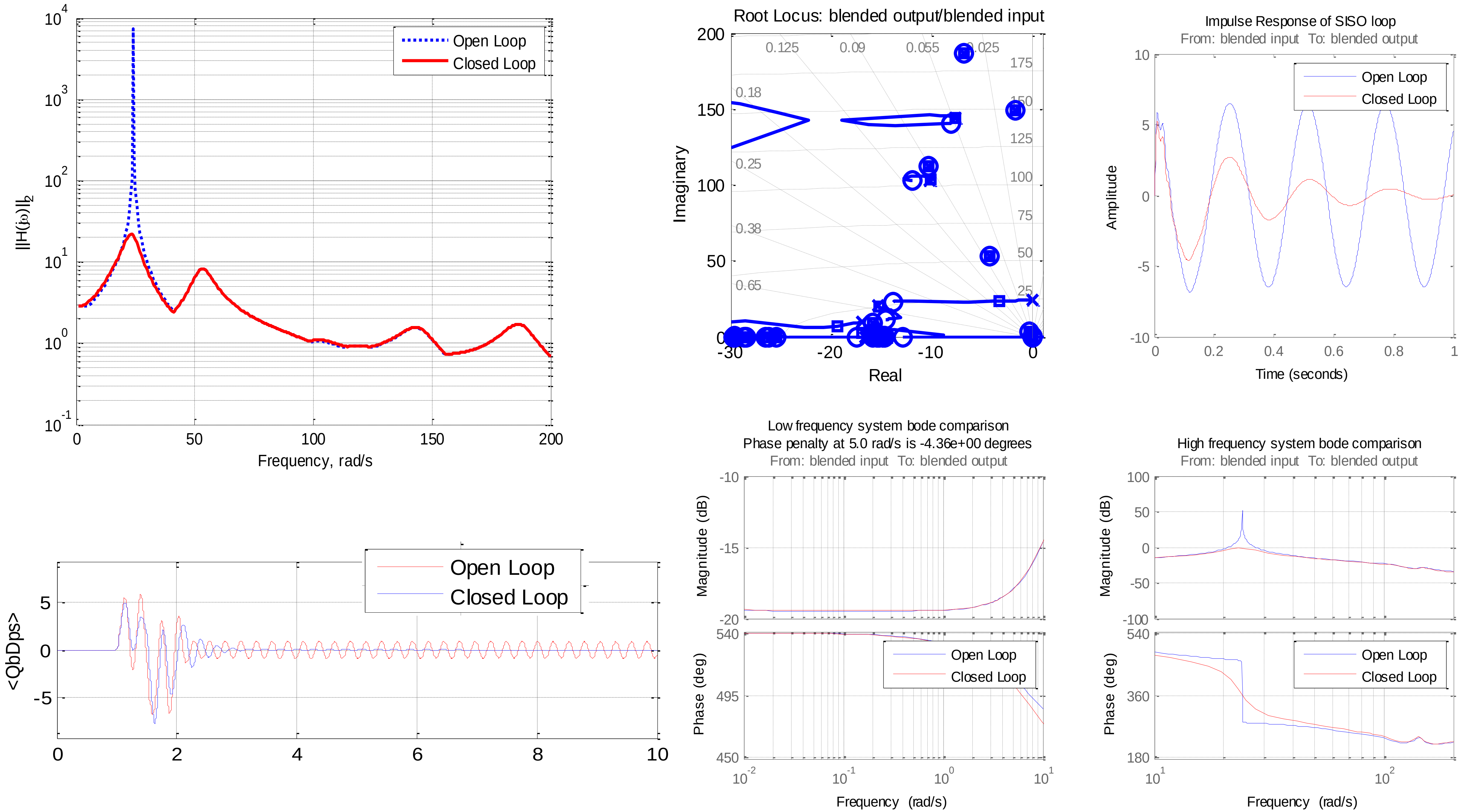
- **M**odal **I**solation and **D**amping for **A**daptive **A**eroservoelastic **S**uppression (**MIDAAS**)
- Distributed sensor and control technique that *utilizes multiple sensors and multiple control effectors* to isolate and damp adverse aeroservoelastic modes.
- The result is effective suppression with *virtually no phase penalty* at lower frequencies leaving rigid body dynamics and performance unaffected.
- Therefore, MIDAAS can be applied completely independently of any existing primary flight control system architecture.
- The MIDAAS solution is robust:
  - Requires minimal computational overhead to synthesize a controller
  - Enables incorporation of a rapid MIMO Subspace System Identification method to make it fully adaptive.
- MIDAAS can be used to suppress multiple problematic modes
- MIDAAS can be applied both adaptive and non-adaptive

MIDAAS application to BFF models

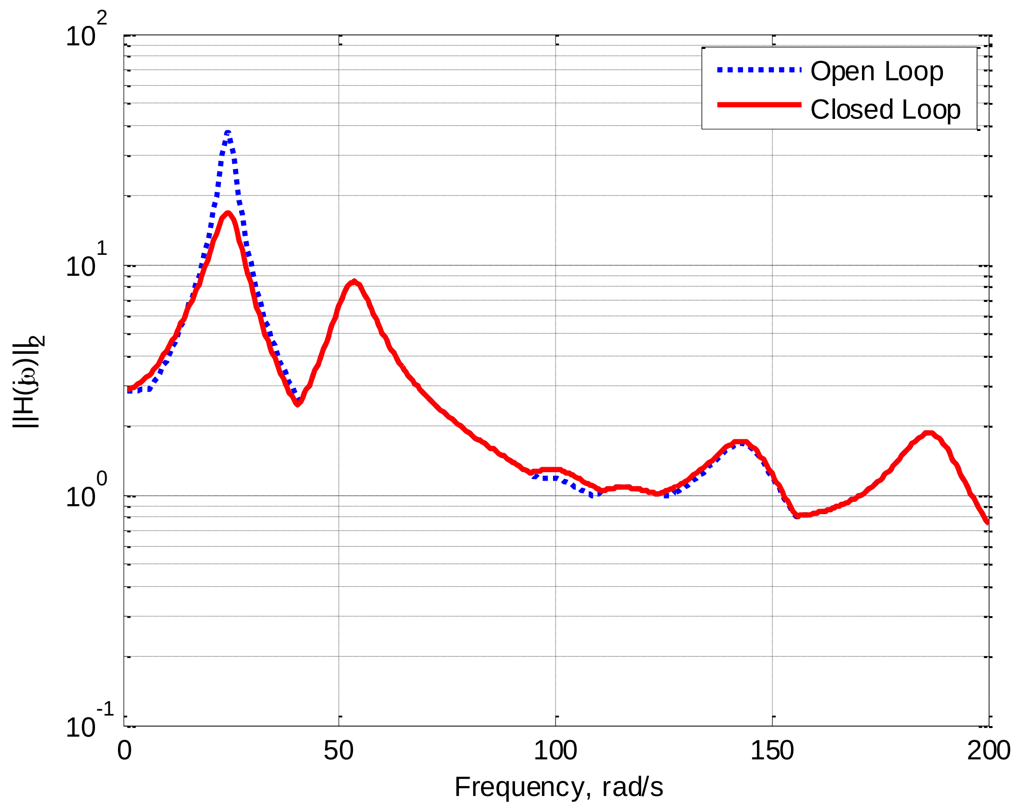
- All 8 trailing edge control surfaces were utilized
- 9 sensors were utilized: body angular rates (p, q, r) and 6 accelerometers
- BFF mode (coupling of SW1B and SP) targeted for isolation and suppression
- Models were used with complete actuator dynamics and sensor dynamics.
- 3 flight conditions analyzed:
  - V = 42 knots (BFF stable)
  - V = 44 knots (BFF unstable)
  - V = 50 knots (BFF unstable)

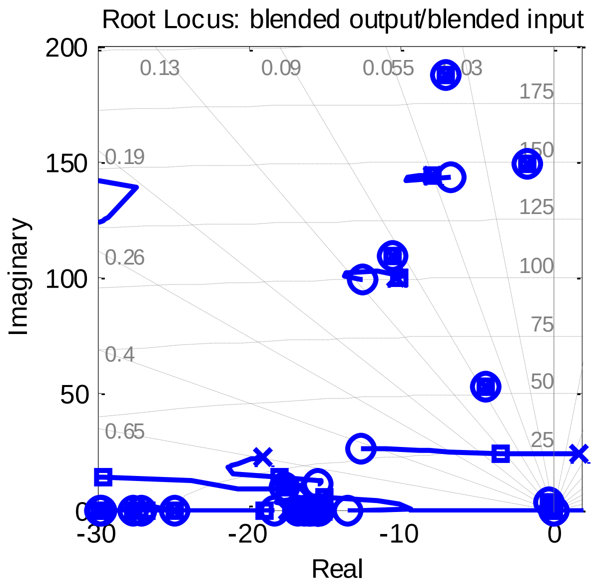


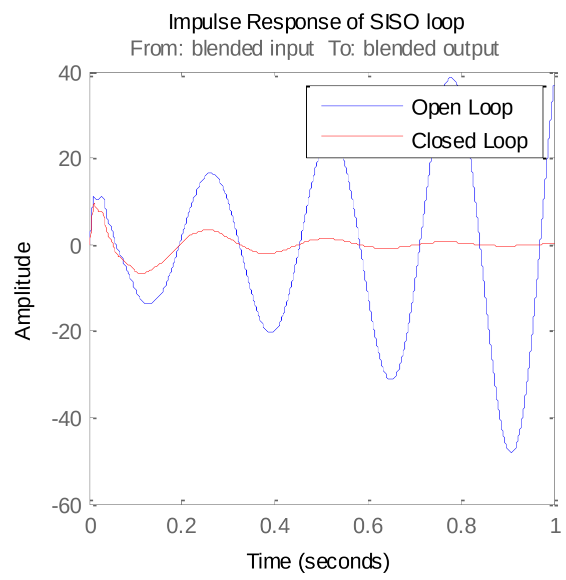
MIDAAS (V = 42 knots)

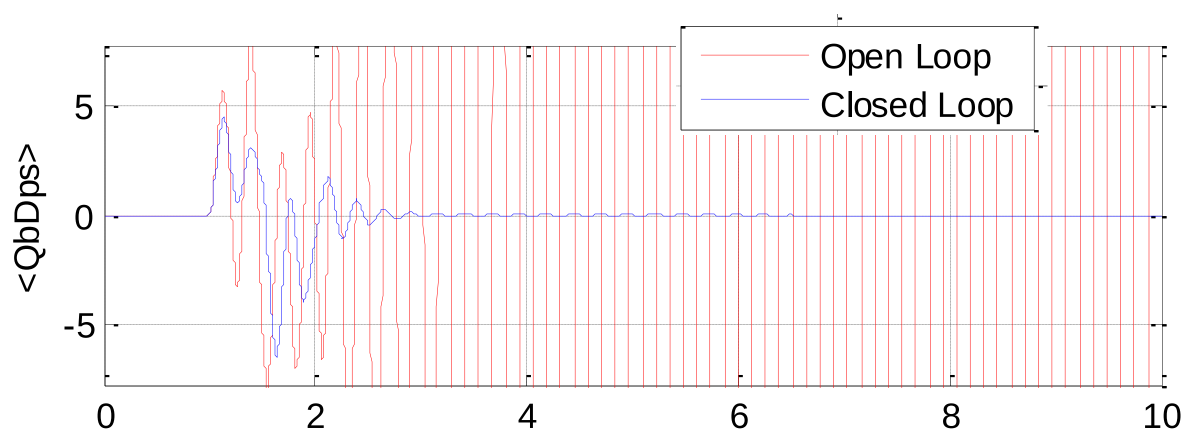


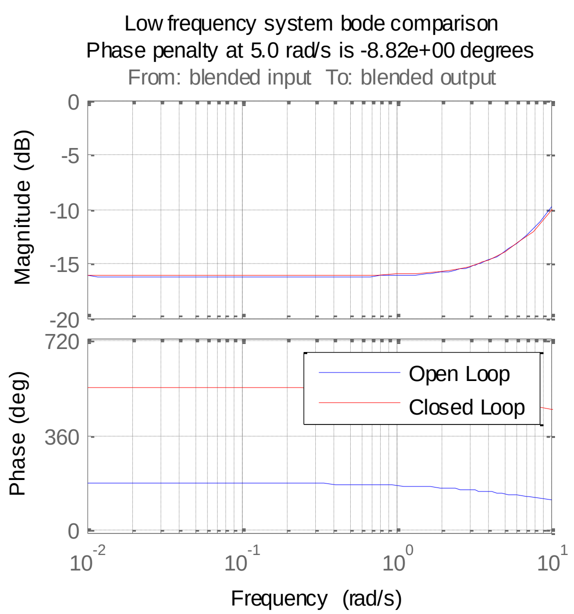
MIDAAS (V = 44 knots)

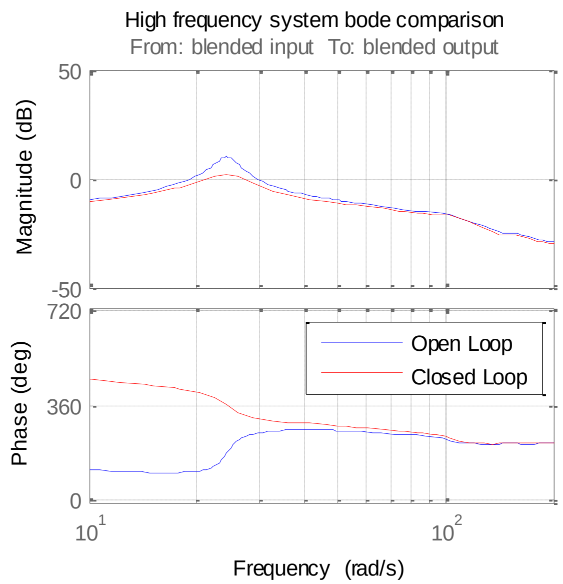




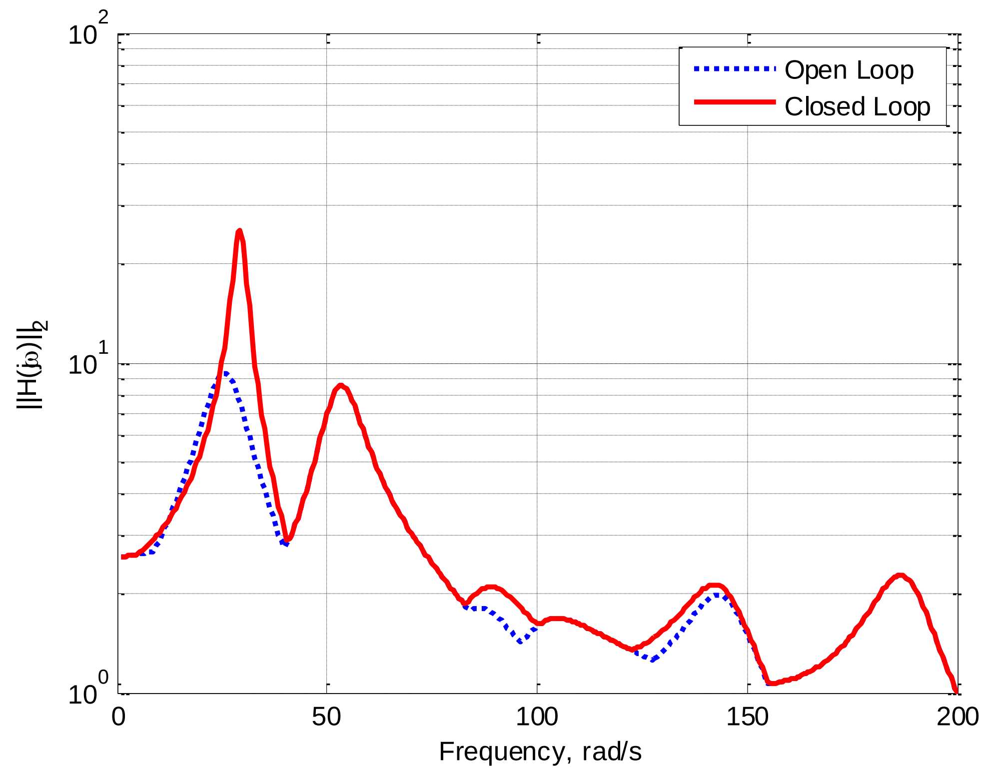


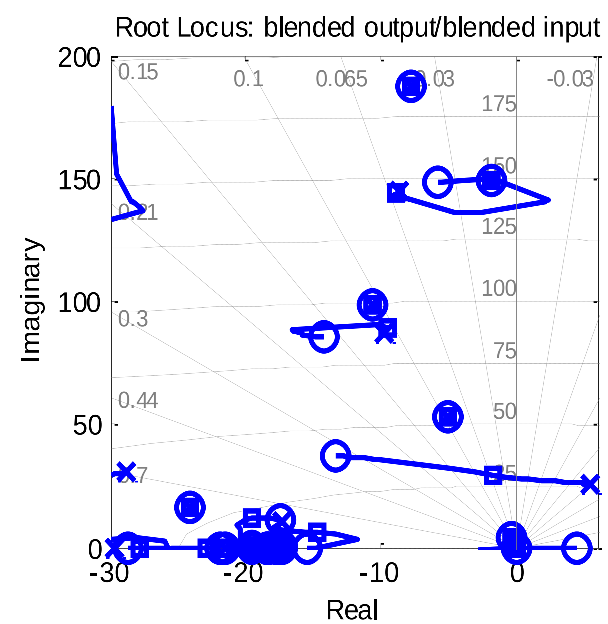


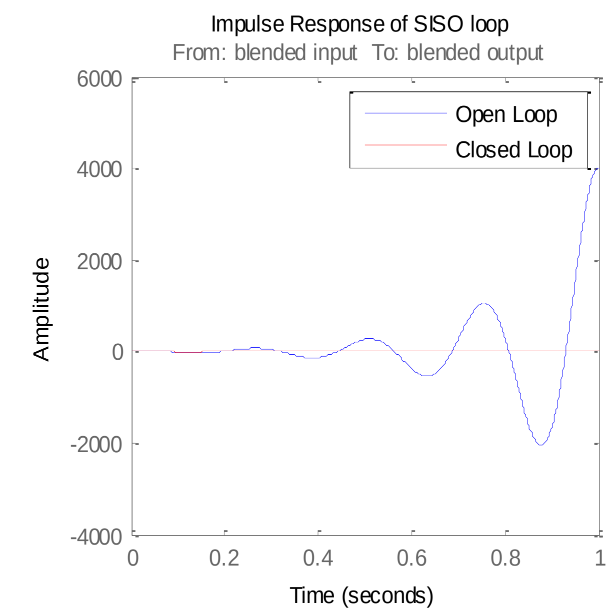


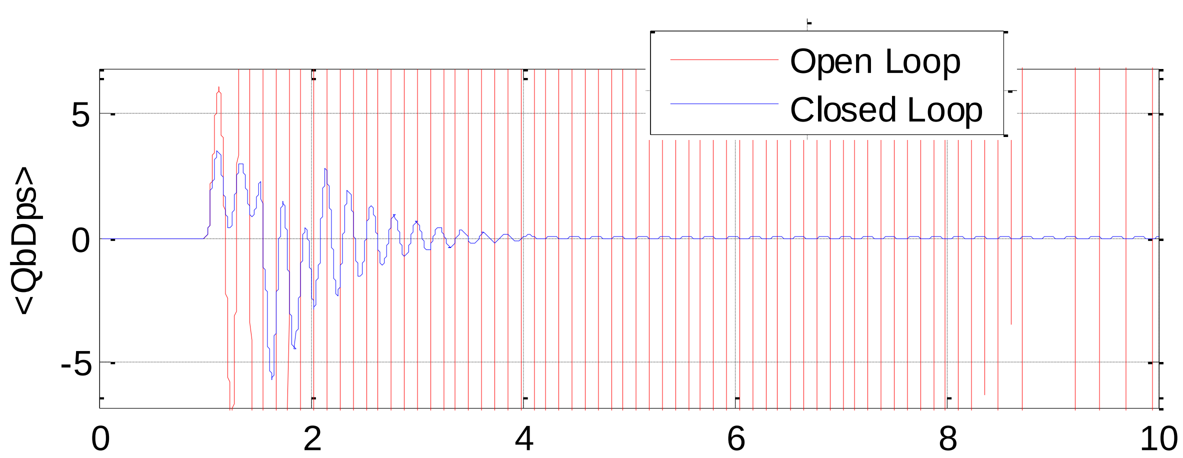


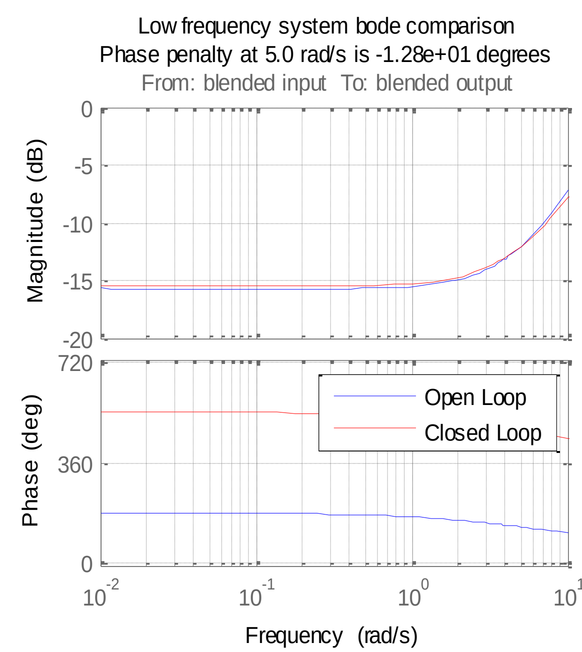
MIDAAS (V = 50 knots)

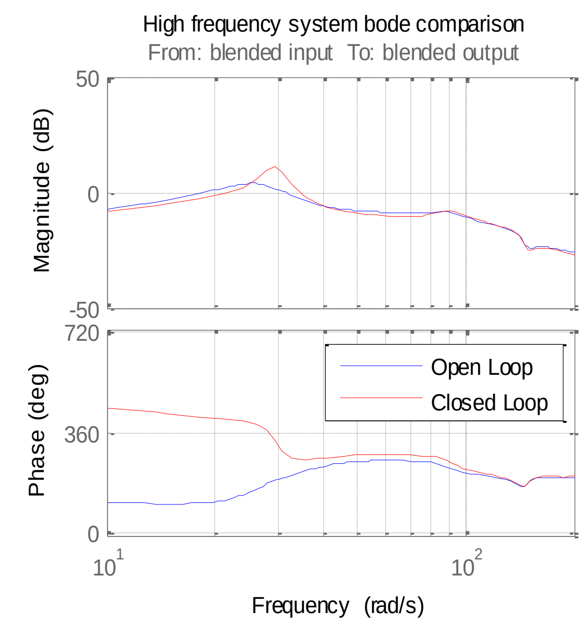






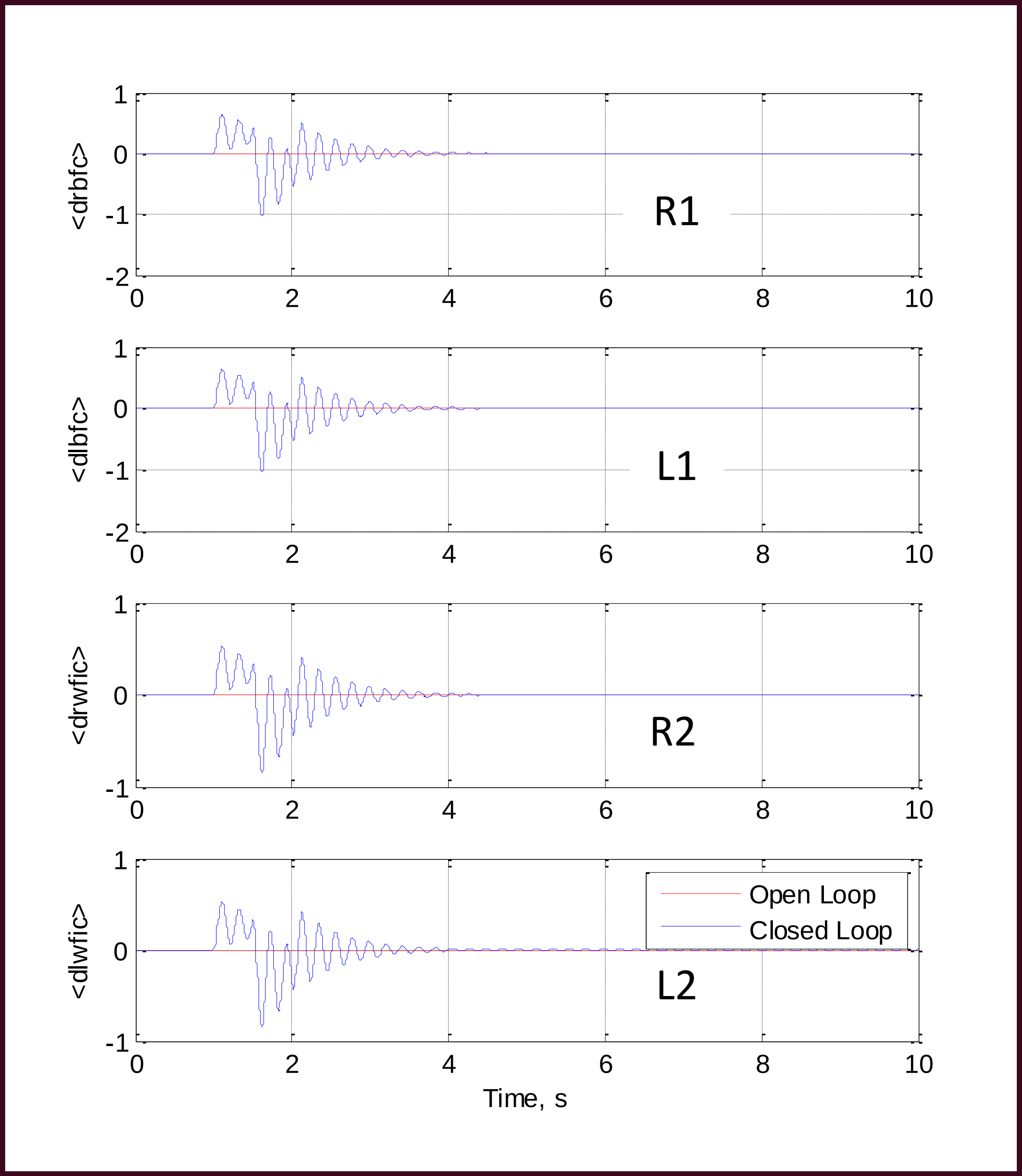


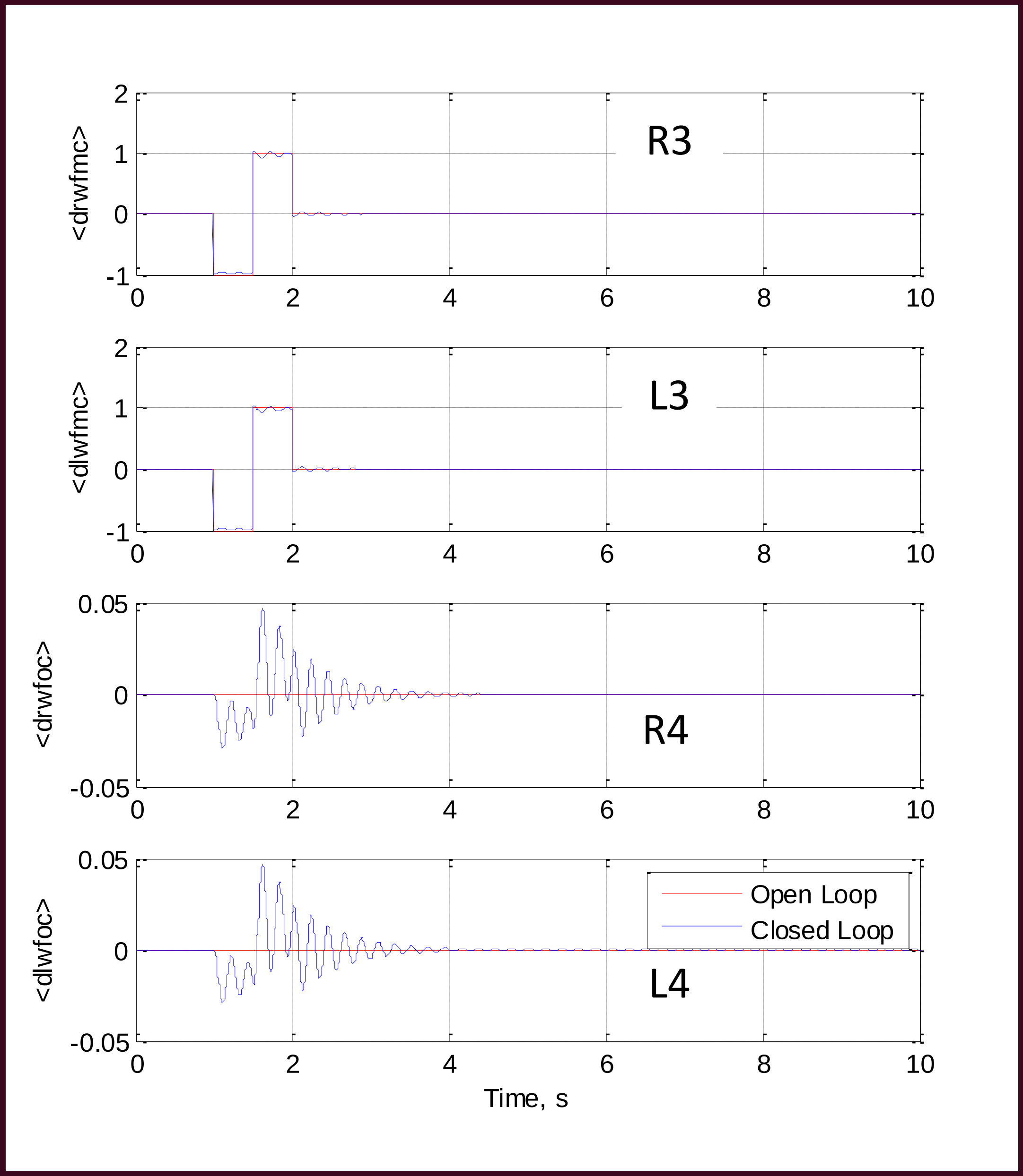




MIDAAS control inputs

- For V = 50 knot case: Doublet input to elevators (1 sec width, 1 degree amplitude)
- Closed loop results show that no surfaces exceed 1 degree





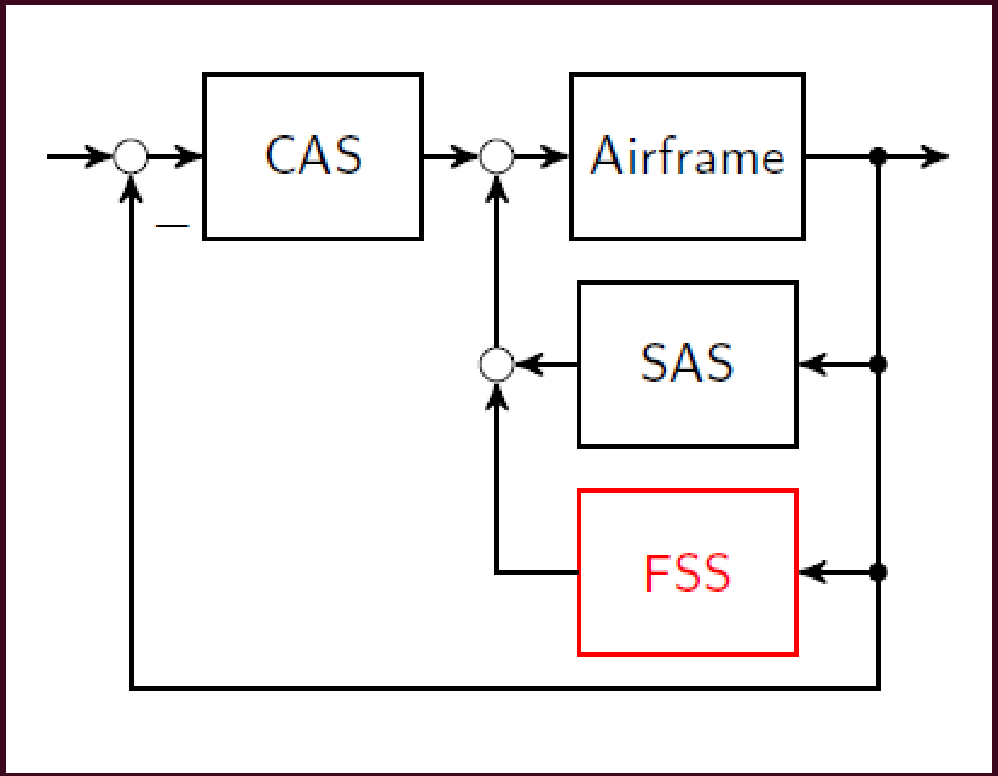
MIDAAS for mAEWing1: Conclusions and Future Plans

- **The BFF mode was effectively isolated and suppressed up to and beyond the flutter boundary.**
- **Given sensor and effector selection: gain feedback is adequate for suppression of the BFF mode.**
- **The models used for synthesis include complete actuator and sensor dynamics.**
- **The MIDAAS solution results in the body flaps doing most of the work: this is intuitive given ILAF and LM's solution.**
- **Future work is ongoing to suppress more modes.**
- **Future work is planned to apply MIDAAS to mAEWing1 models when available.**

Danowsky, B. P., Thompson, P. M., Lee, D. C. and Brenner, M., "**Modal Isolation and Damping for Adaptive Aeroservoelastic Suppression**," AIAA Paper 2013-4743, *AIAA Atmospheric Flight Mechanics Conference*, August 2013.

LPV Control for Flutter Suppression

- Flutter beyond 44 knots airspeed
- Provide stability and damping of body freedom flutter and bending torsion modes
- Outboard and body flaps as effectors
- Six accelerometers as sensors

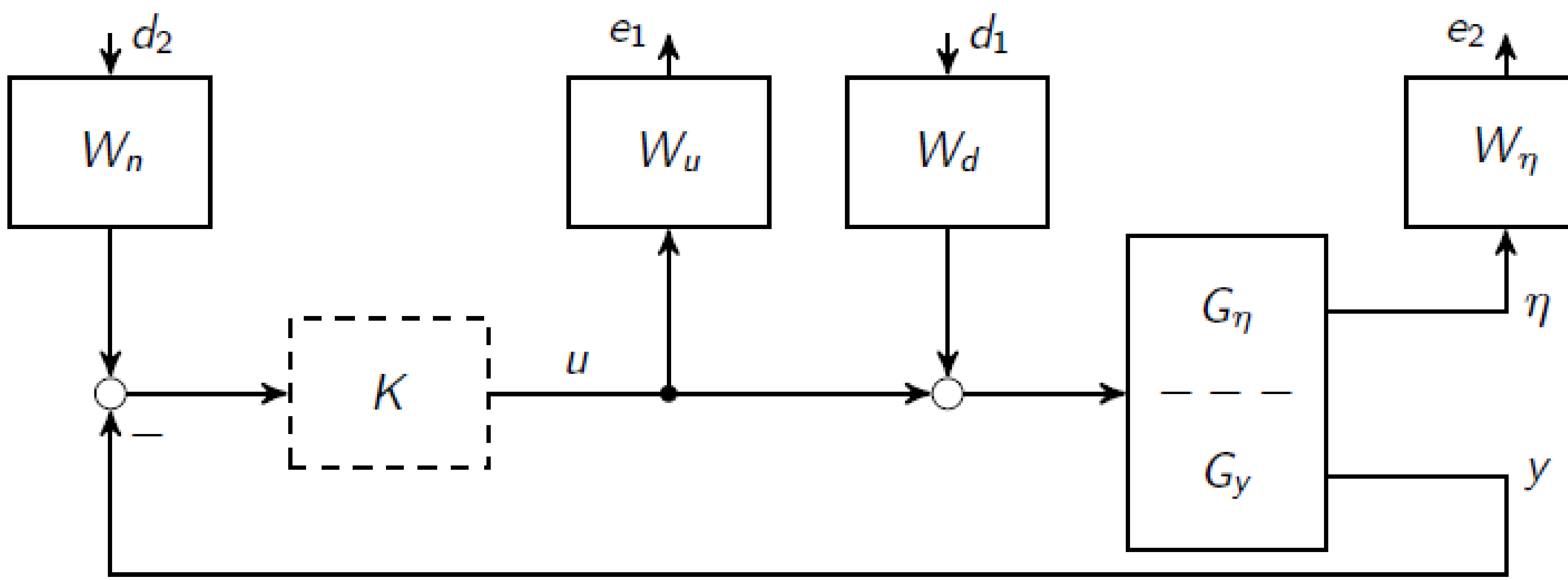


CAS command augmentation system
SAS stability augmentation system
FSS flutter suppression system

Preliminary Design

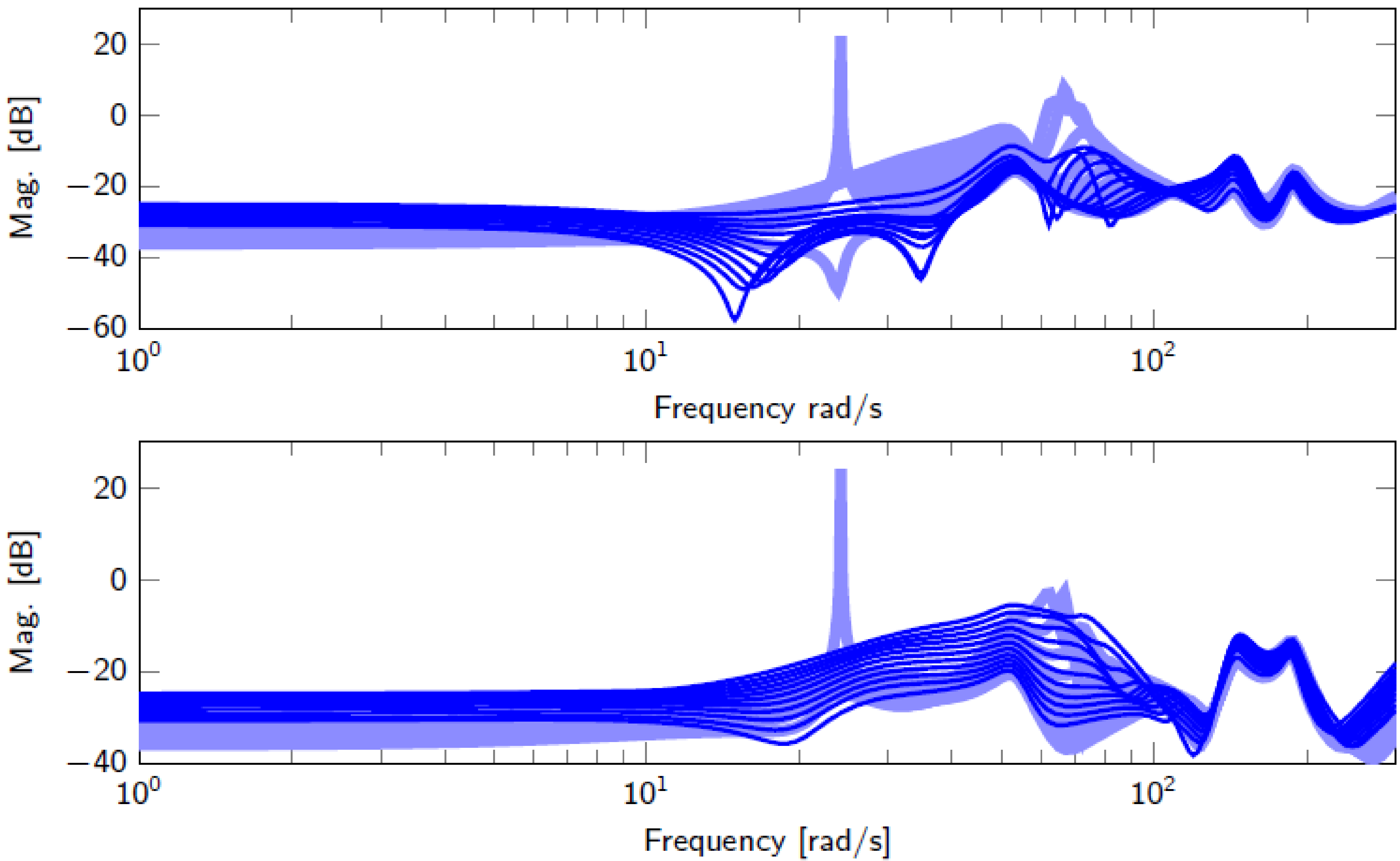
- Uses reduced order model for synthesis
- Design from 40 to 60 knots

Performance Specification



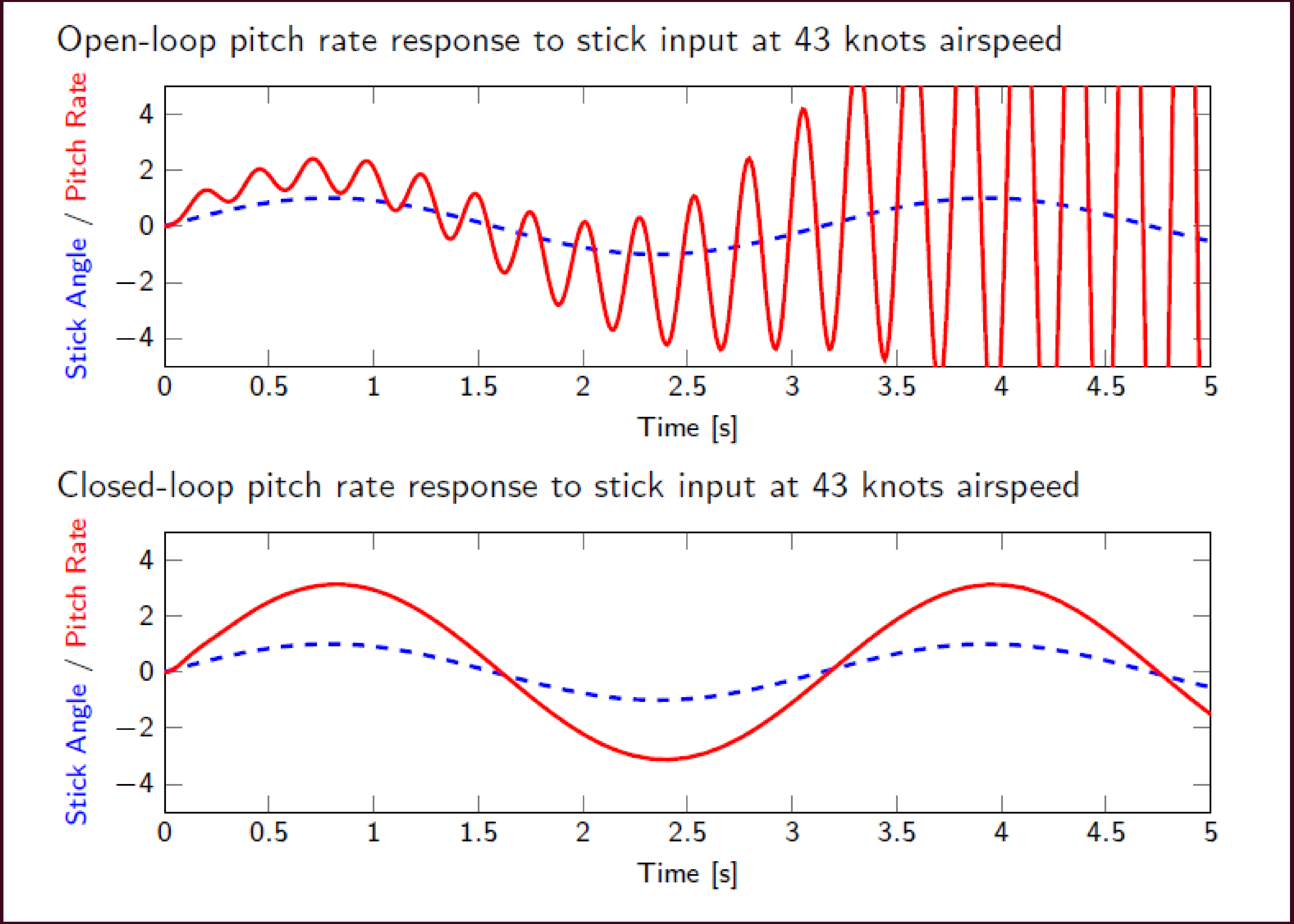
$$\begin{bmatrix} e_1 \\ e_2 \end{bmatrix} = \begin{bmatrix} W_u & 0 \\ 0 & W_\eta \end{bmatrix} \begin{bmatrix} -T_i & S_\mathrm{i}\,K \\ G_\eta\,S_\mathrm{i} & G_\eta\,S_\mathrm{i}\,K \end{bmatrix} \begin{bmatrix} W_d & 0 \\ 0 & W_n \end{bmatrix} \begin{bmatrix} d_1 \\ d_2 \end{bmatrix}$$

Bode Results from Flaps to Accelerometers

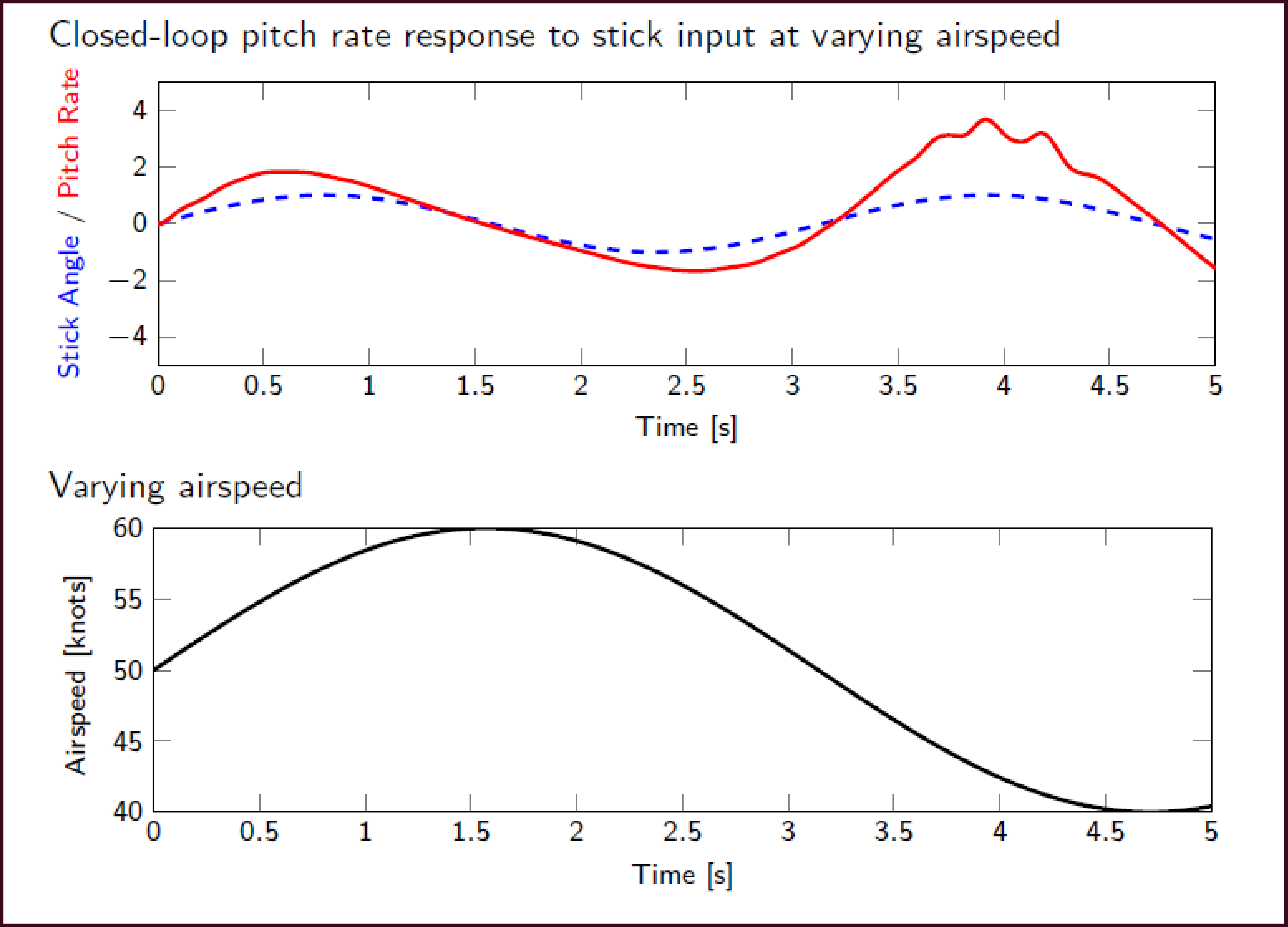


Frequency response of full order open-loop model ( ) and closed-loop ( ).

Linear Time Simulations

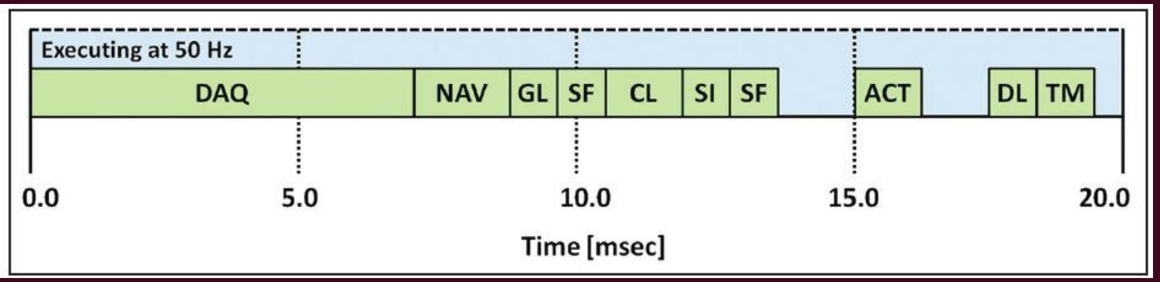


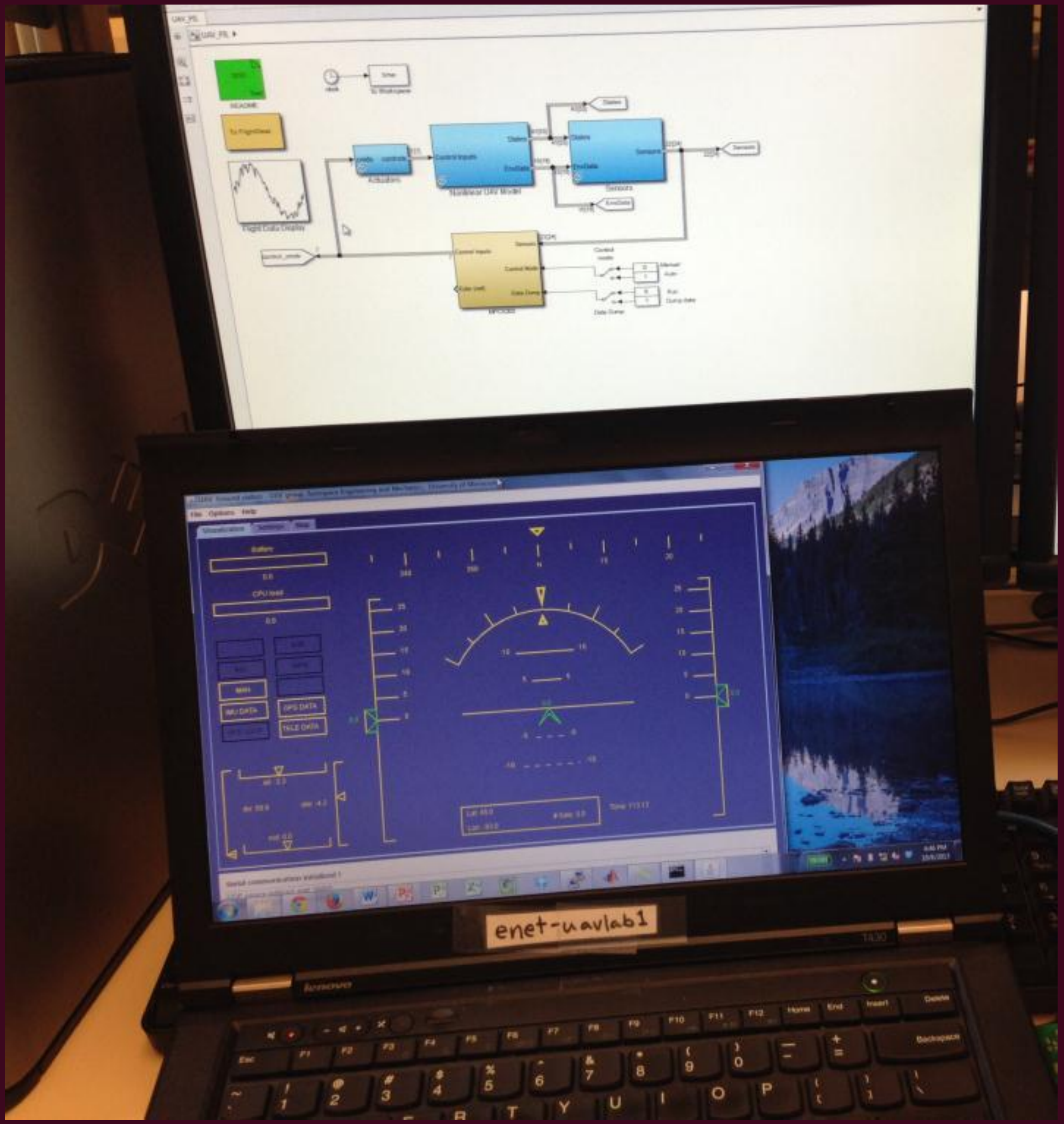
Linear Parameter Varying Simulation



Software

- Modular software architecture
- Hard real-time 50 Hz framerate
- Lengthy flight history
- Currently flying preliminary software on rigid wing set
  - Pitch damper
  - Onboard Excitation System
- V&V Process
  - Validate control law performance using CFD/CSD simulation
    - Ensures that control law is robust to nonlinearities
  - HIL testing against ROM simulation
    - Ensures that controller performance is not degraded running on flight hardware





Test Plan

- 3211 and multisine inputs on all surfaces at 30 and 40 knots
  - Gather aerodynamic data to validate and update models
- Open envelope, back off 5 knots and 3211 excitations at 5 knot intervals to clear the envelope up to 65 knots
  - Demonstrate suppression of first flutter mode
- Back off to 60 knots and vary outboard surface trim position to demonstrate shape change
  - Validate shape change using photogrammetry

Programmatic Risk

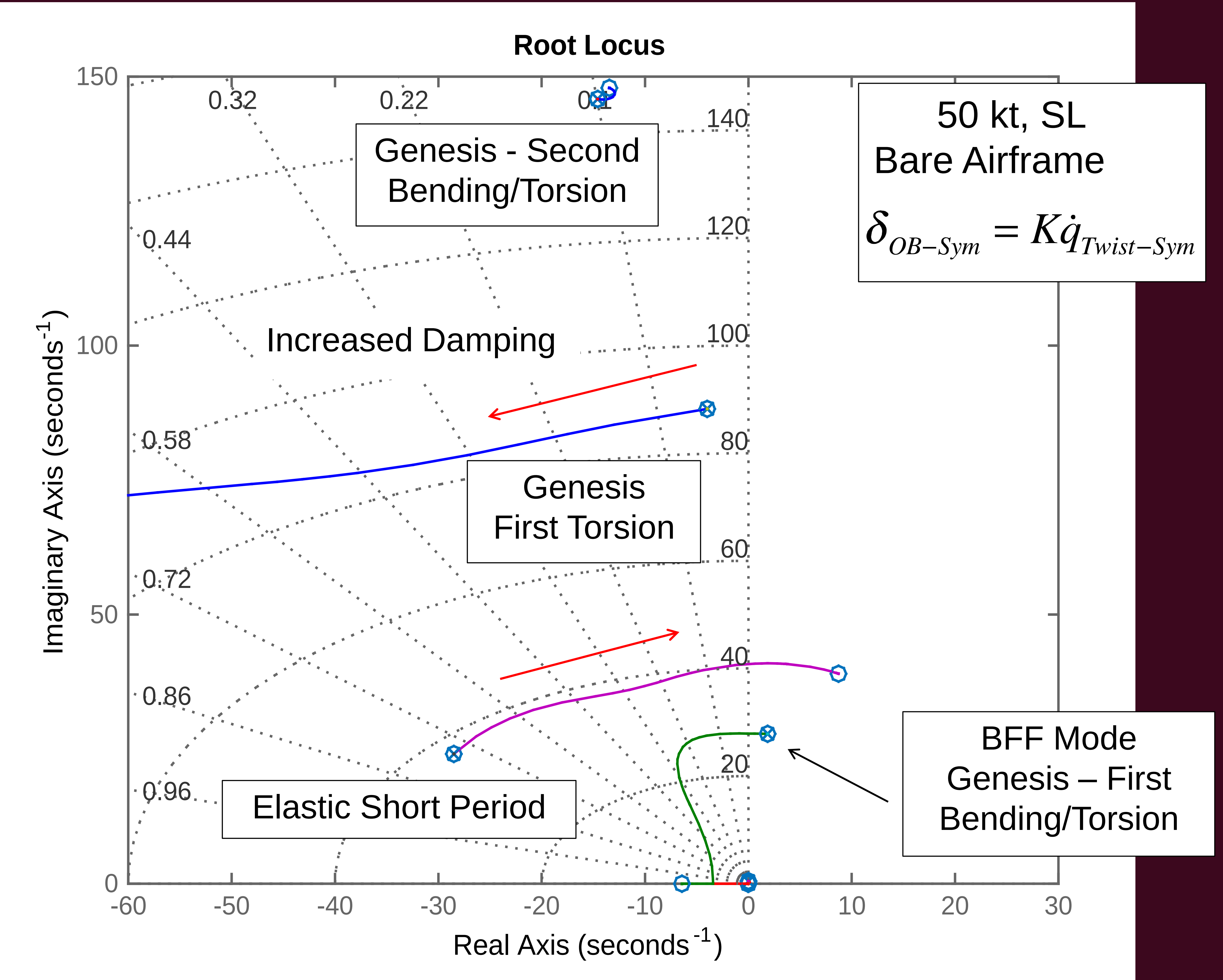
- Time constrained schedule
  - Buying down risk
    - Center body foam
    - Accelerometers and anti alias filters
  - Leveraging expertise
    - CFD/CSD and FD modeling
    - Control law design
- Incorrect flutter speed prediction
  - Additional speed margin in envelope
  - Add point masses
- Potential of aircraft damage during landing
  - Developing autoland flight control laws
  - Building two wing sets

Current Status

- Expected build and component testing complete in mid-April
  - Spar construction and testing complete
  - Actuator testing complete
  - Identifying appropriate accelerometer
  - Wing construction in work
- Modeling and control law development in progress
  - Preliminary work done with BFF models
  - Developing mAEWing1 models and control laws, expected to be complete in mid-April
  - Update with mass properties and GVT testing
- Flight testing rigid wing vehicle
  - Operating procedures
  - OBES excitation design
  - Rigid body aero identification
  - Rigid body control law design and validation

Second Flutter-Mode Suppression

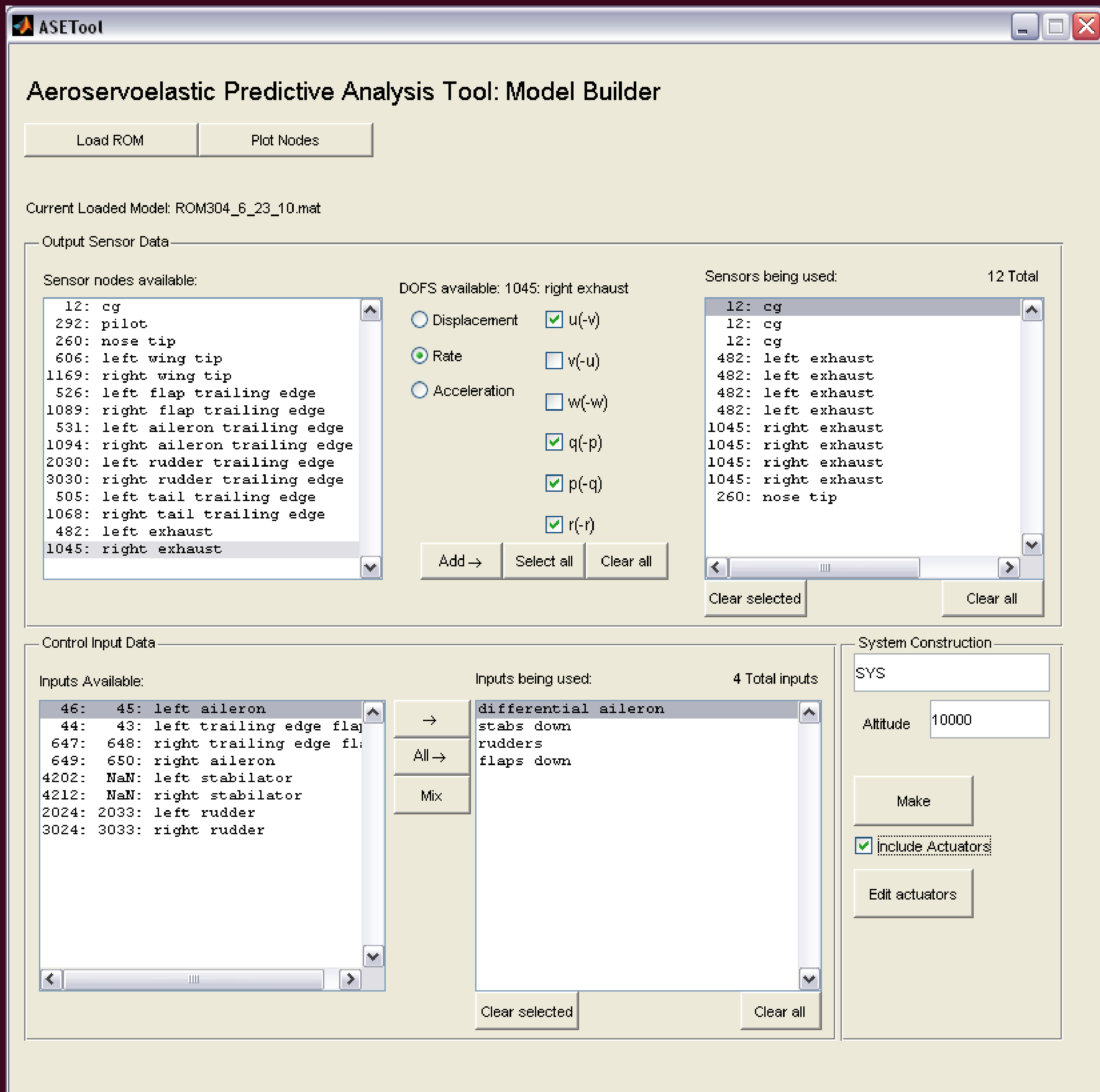
Wing-Tip Twist to Outboard Flaps

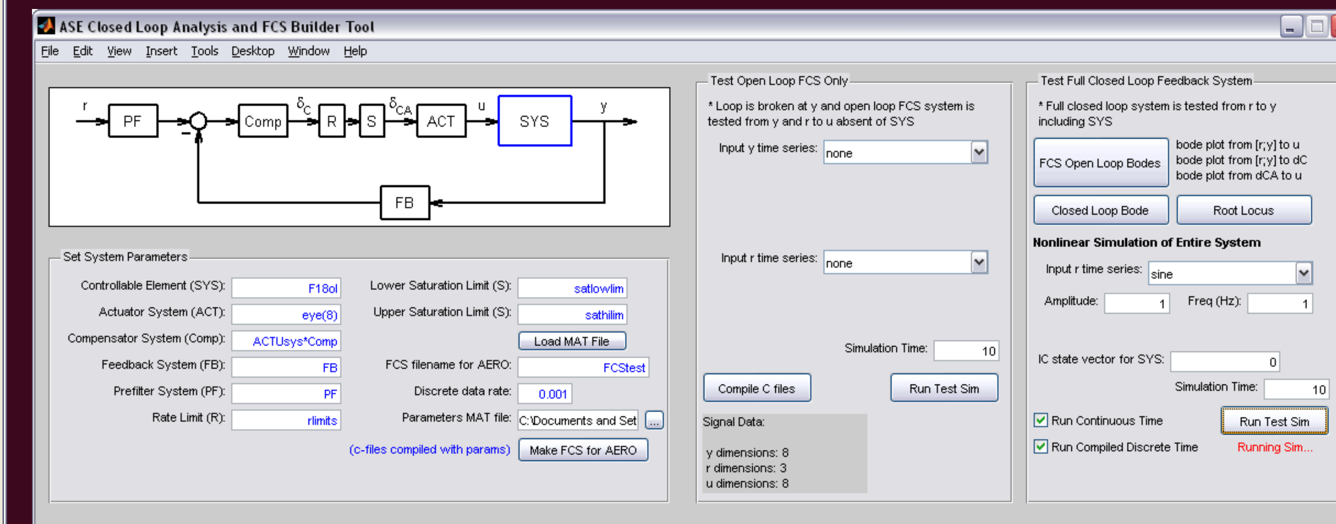


Casting sensors into the proper frame

- As noted, sensors based on nodal response will be in the inertial frame. True aircraft measure data in the body-fixed frame.
- More accurately, since the aircraft is flexible, the sensors will each have their own local “node” frame.
- Transforming from inertial to nodal coordinates must consider the accelerating (rotating) nodal frame. Conveniently, this transformation can be defined with a linear approximation.

Matlab-based Software Tools





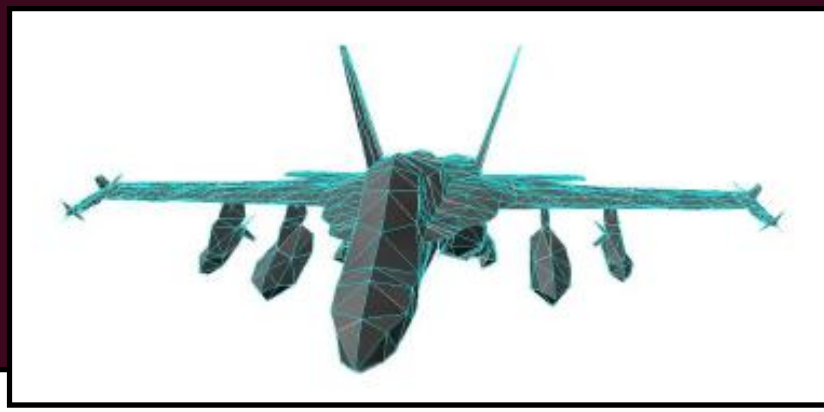
FCS Analysis and Import Tool:

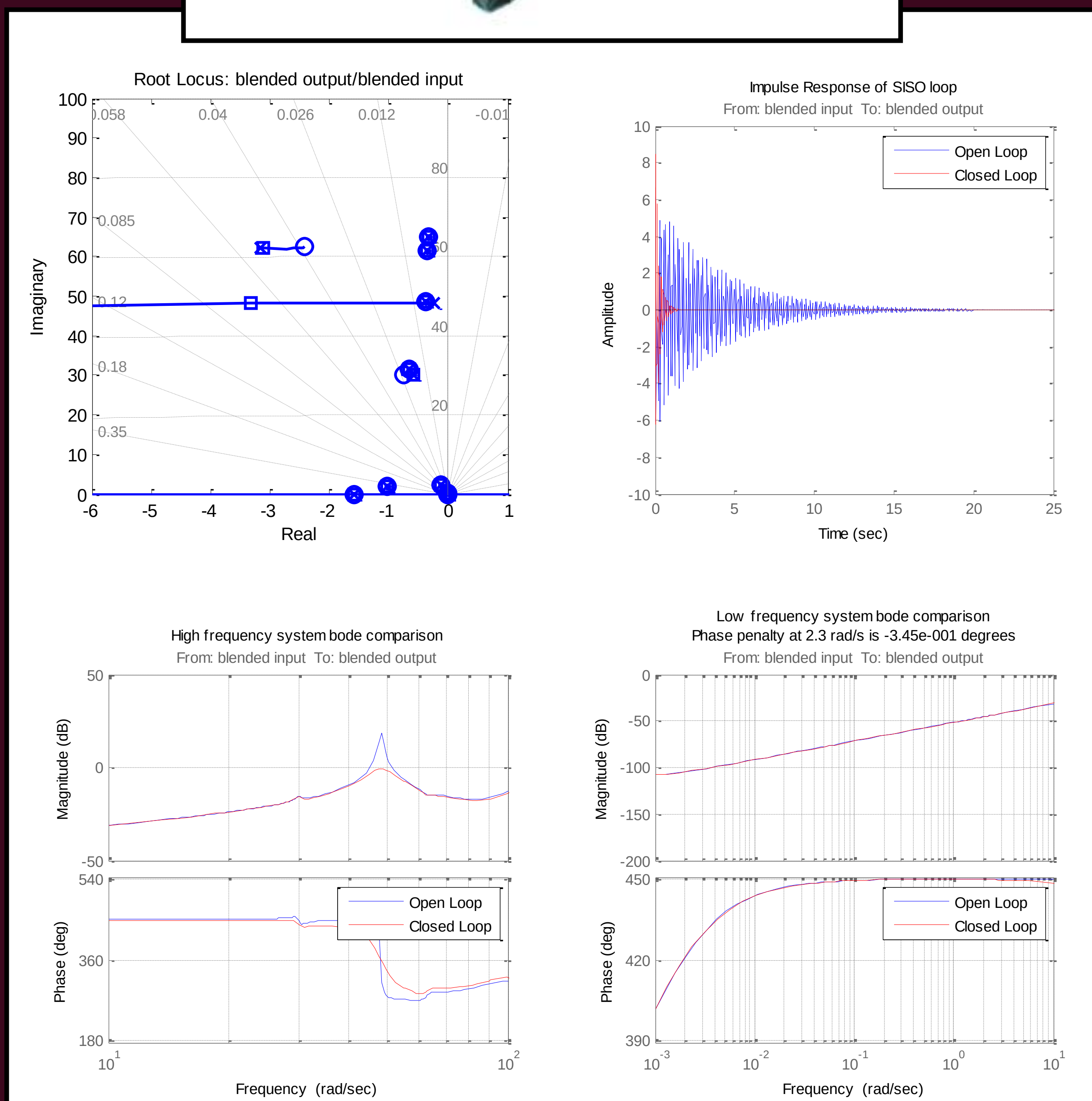
- Incorporate designed control laws with the high fidelity CFD/CSD model.
- Include nonlinearities in the form of rate limits and saturations.
- Controllers and compensators designed using the IOROM are ported and C-code is auto generated.
- Code is compiled and tested with the IOROM.
- All interface code and files are auto generated in a form that can be easily incorporated with the full order AERO model for high fidelity simulation on a parallel computing cluster.

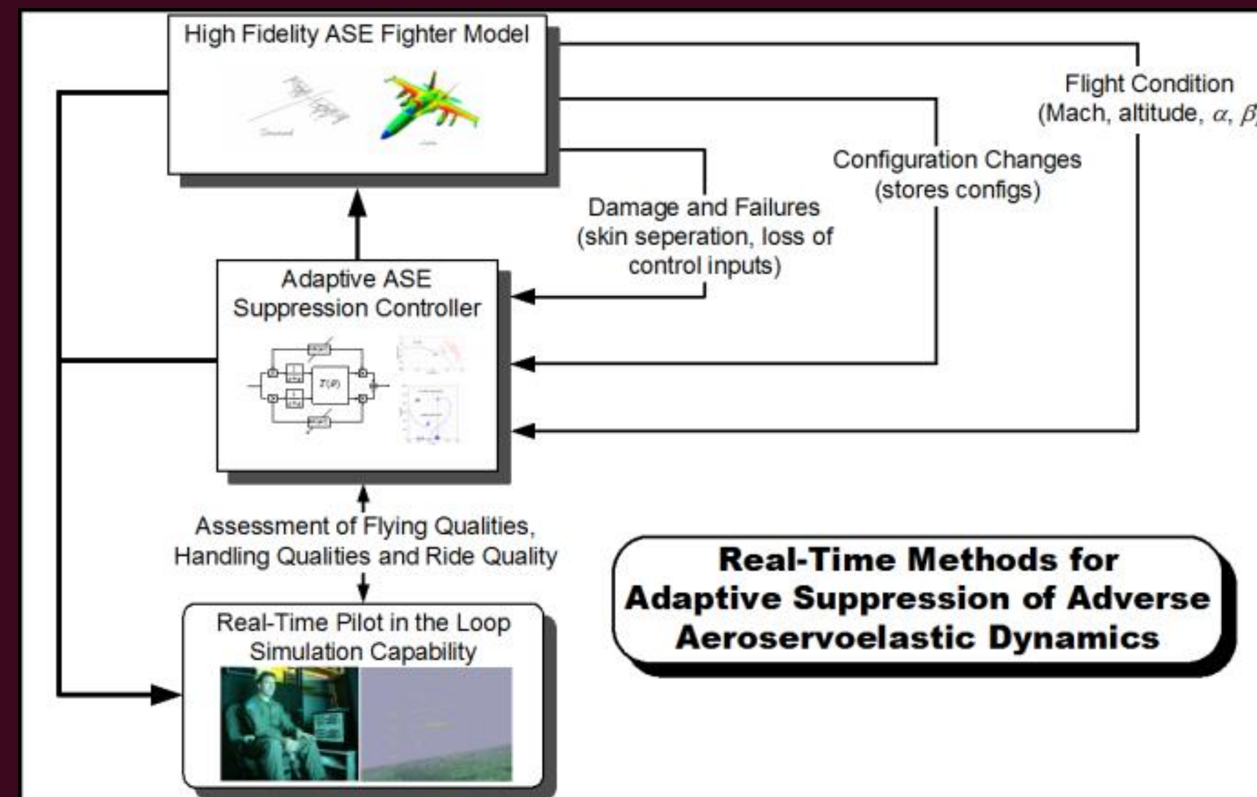
LTI Model Builder Tool:

- Import ROMs exported from AERO software
- Construct complete I/O LTI ASE system using sensors from any structural node and control inputs in the form of equal and opposite moments at other nodes.
- Ability to incorporate actuator models.
- Output is ideal for control design and/or real-time simulation.

Modal Isolation and Damping for Adaptive Aeroservoelastic Suppression







MIDAAS can suppress multiple modes

- MIDAAS can be effectively utilized to damp multiple adverse modes.
- Each loop is closed individually.
- The effective MIDAAS gain is the sum of the individual gains.